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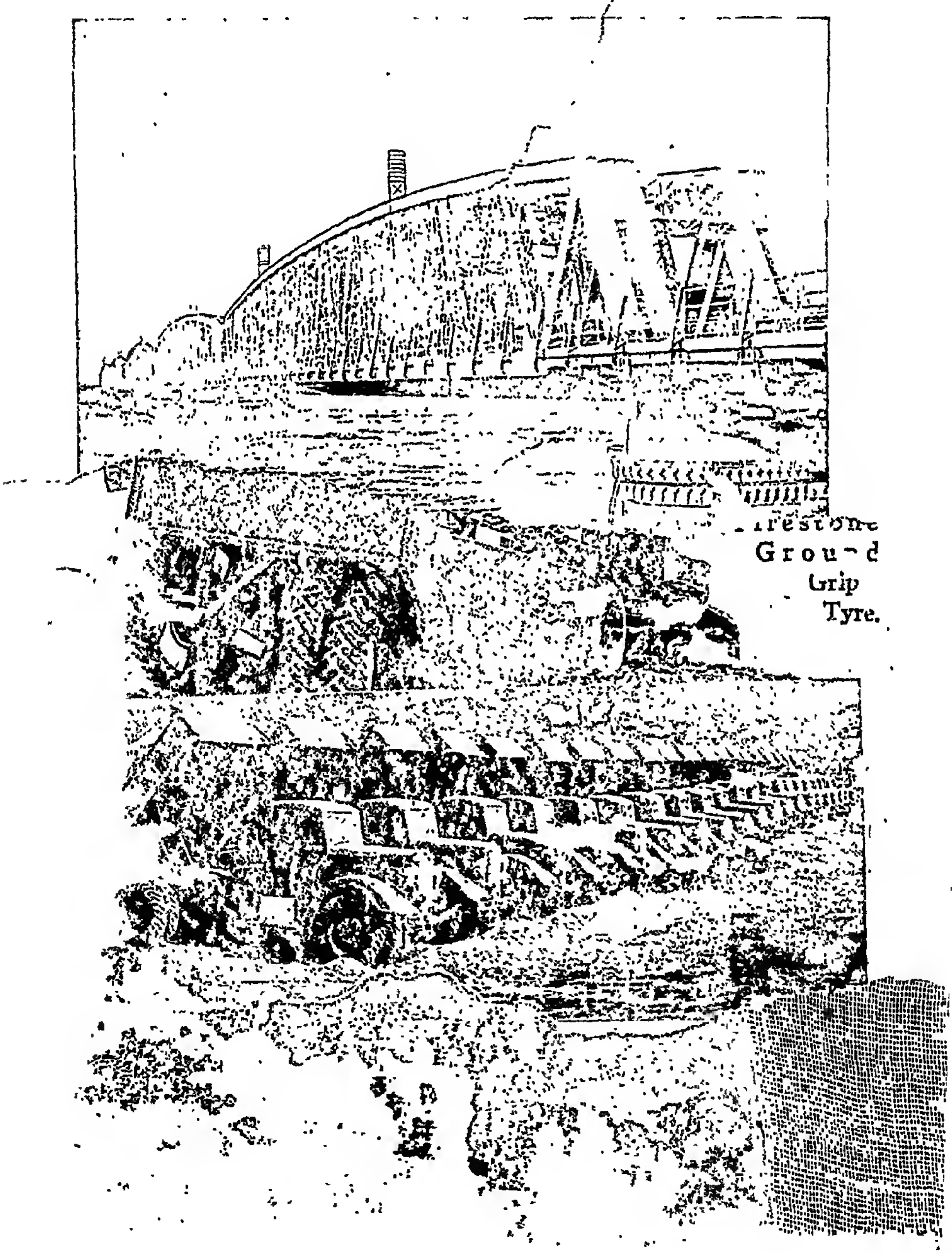

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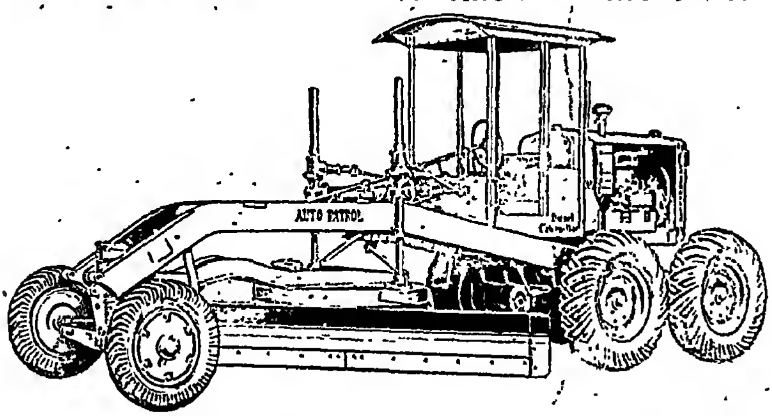
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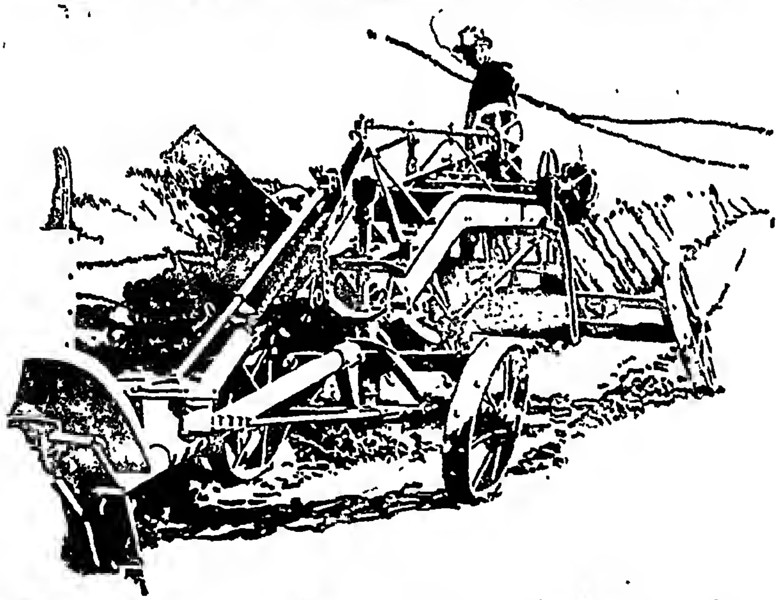

Indian Roads Congress.

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(1937)

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28. Mr. S. BASHIRAM, Superintending Engineer, II Circle, Public Works Department, Ambala.

29. Mr. N. V. MODAK, City Engineer, Bombay Municipality, Hornby Road, Fort, Bombay.

30. Lieut.-Colonel H. C. SMITH, O.B.E., M.C., General Secretary, Indian Roads and Transport Development Association, Bombay.

Proceedings of the Third Meeting of the Indian Roads Congress.

Vol. III Lucknow February 1937.

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APPENDICES.

Proceedings of the Third Meeting of the Indian Roads Congress held at Lucknow on February 22 to 24, 1937.

The Third Session of the Indian Roads Congress commenced at 11 A.M. on February 22, 1937 in the Municipal Hall at Lucknow. The following members of the Congress were present: —

PROVINCES.

Madras.

Mr. A. Nageswara Ayyar, Special Engineer for Road Development, Madras.

Mr. V. S. Srinivasa Raghava Achariyar, District Board Engineer, South Arcot, Cuddalore.

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Mr. P. G. Mathew, District Board Engineer, Bobbili, Vizagapatam District.

Mr. T. Lokanatha Mudaliyar, District Board Engineer, Negapatam.

Mr. P. K. Mukherji, District Board Engineer, Cocanada.

Bombay.

Mr. R. A. Fitzherbert, I.S.E., Deputy Secretary to the Govt. of Bombay, P. W. D.

Mr. N. V. Modak, B. E., M. Inst. C. E., M. R. San. I., etc., City Engineer, Bombay Municipality.

Mr. E. A. Nadirshah, Ag. Hydraulic Engineer, Bombay Municipality.

Bengal.

Mr. C. P. M. Harrison, Chief Engineer, P. W. D. Bengal, Calcutta.

Mr. A. K. Datta, Consulting Engineer & Master Builder, Calcutta.

Rai Sahib K. C. Gue, District Engineer, Jalpaiguri.

United Provinces.

Rai Bahadur Chhuttan Lal, Chief Engineer (retired), P. W. D., B. & R. Branch.

Lt. Col. W. deH. Haig, D.S.O., Chief Engineer, P. W. D., B. & R. Branch.

Mr. C. F. Hunter, I.S.E., Deputy Chief Engineer, P. W. D., B. & R. Branch.

Mr. L. B. Gilbert, I.S.E., Deputy Chief Engineer, P. W. D., B. & R. Branch.

Mr. W. F. Walker, I.S.E., Executive Engineer, Agra.

Mr. A. C. Mukerjee, I.S.E., Executive Engineer, Lucknow.

Mr. Mahabir Prasad, I.S.E., Professor, T. C. E. College, Roorkee.

Mr. R. K. Sarkar, Municipal Engineer, Lucknow.

Mr. C. C. Bagchi, Sub-Divisional Officer, Lucknow University.

Punjab.

Mr. S. G. Stubbs, O.B.E., I.S.E., Chief Engineer and Secretary to the Govt. of the Punjab, P.W.D., Buildings and Roads Branch.

Mr. R. Trevor Jones, I.S.E., Superintending Engineer, Roads, Punjab P. W. D., Lahore.

Mr. S. Bashiram, I.S.E., Superintending Engineer, Ambala.

Mr. R. L. Sondhi, I.S E., Executive Engineer, P. W. D., Simla.

Mr. Bishamber Dayal, District Engineer, Rohtak.

Bihar.

Mr. W. L. Murrell, I.S.E., Superintending Engineer, Chota Nagpur Circle, Ranchi.

Mr. S. K. Ghose, Assistant Engineer, Sitamarhi Court, Dumra.

Central Provinces.

Mr. B. St. J. Newton, Executive Engineer, Lower Mahanadi Divn., Raipur.

Mr. G. M. Mckelvie, Executive Engineer, Akola.

Assam.

Mr. Ali Ahmad, I.S.E., Superintending Engineer, P. W. D., Shillong.

Mr. R. L. Varma, I.S.E., Executive Engineer, P. W. D., Tezpur.

North-West Frontier Province.

Capt. J. R. Hainsworth, R.E , Executive Engineer, Peshawar.

Orissa.

Mr. J. Bakshi, Executive Engineer, Southern Division, Cuttack.

Mr. G. P. Ray, District Board Engineer, Puri.

Sind.

Mr. H. B. Parikh, L.C.E , M.I.E , (Ind), I.S.E., Special Road Engineer in Sind, Karachi.

Mr. G. B. Vaswani, Assistant Engineer, Roads, Karachi Municipality.

Burma.

Mr. H. Hughes, I.S.E., M. Inst. C. E., Superintending Engineer, P. W. D., B. & R. Branch, Rangoon.

Delhi.

Mr. A. W. H. Dean, M.C., Superintending Engineer, Central P. W. D., New Delhi.

Mr. S. N. Chakravarti, Municipal Engineer, Delhi.

Mr. Ishtiaq Ali, Assistant Municipal Engineer, Delhi.

Mr. J. N. Das Gupta, Assistant Municipal Engineer, Delhi.

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Captain R. C. Clayton, Garrison Engineer, Wana.

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Mr. K. G. Mitchell, C.I.E., Consulting Engineer to the Govt. of India (Roads).

Professor Raja Ram, Consulting Engineer to the Malaria Survey of India, Delhi.

Mr. Jagdish Prasad, Assistant to the Consulting Engineer to the Govt. of India (Roads), & Secretary, Indian Roads Congress, Delhi.

Mr. E. F. G. Gilmore, Government Test House, Alipore.

STATES.

Central India.

Mr. Prem Nath Bhalla, District Engineer, Garoth, Holkar Government.

Mr. Taracharan Guo, B.Sc., B.E, C.E., Chief Engineer, Rewa Darbar, Rewa.

Mr. C. P. Saksena, B.C.E., Assistant Engineer, Rewa Darbar, Rewa.

Rajputana.

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Mr. Arifuddin, Superintending Engineer, His Exalted Highness the Nizam's P. W. D., 4th Circle, Hyderabad (Deccan).

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Deccan States.

Mr. V. A. Dighe, L.C.E., Chief Engineer, Janjira State, Janjira.

Mr. V. J. Kunte, B.E., State Engineer, Jamkhandi.

Mr. D. G. Sowani, Executive Engineer, Kolhapur.

Gujarat States & Baroda.

Mr. M. T. Adalja, L.C.E , Chief Engineer of Baroda State.

Mr. M. R. Patel, B A., L.C.E., Executive Engineer, Navsari Division, Baroda State.

Eastern States.

Mr. F. D. Wellwood, Chief Engineer, Mayurbhanj State.

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Mr. H. E. Ormerod, The Cement Mrakesting Co. of India Ltd., Bombay.

Mr. J. P. Anderson, The Dunlop Rubber Co , (India) Ltd., Calcutta.

Mr. J. W. Smith, Standard Vacuum Oil Co., Calcutta

Lt.-Col. H. C. Smith, General Secretary, Indian Roads & Transport Development Association Ltd , Bombay.

Mr. C. D. N. Meares, Standard Vacuum Oil Co., Calcutta.

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Mr. I. N. Khanna, Standard Vacuum Oil Co., Delhi.

Mr. A. Burns Lawson, M. Inst. C.E., The Hindustan Construction, Co., Ltd., Bombay.

Mr. M. D. Bharucha, B.E., The All-India Construction Co., Ltd., Bombay.

Mr. W. A. Griffiths, Burmah Shell Oil & Distributing Co., Ltd.; Calcutta.

Mr. H. James, Burmah Shell Oil & Distributing Co., Ltd , New Delhi.

Mr. A. Stuart Lewis, The Concrete Association of India, Calcutta.

Mr. W. J. Turnbull, Shalimar Tar Products (1935) Ltd., Bombay

Mr. N. Dass Gupta, B.E., Standard Vacuum Oil Co , Calcutta.

Mr. A. V. Gharpure, Hume Pipe Company, Delhi.

Mr. M. M. Doshi, Hume Pipe Company, Lucknow.

Mr. V. M. Meswani, Hume Pipe Company, Bombay.

Mr. W. H. Kerr, Bitumen Emulsions (India) Ltd.

Mr. M. E. Lloyd, Standard Vacuum Oil Company, Calcutta.

Mr. A. A Waugh, I.C.S., Secretary to the Government of the United Provinces Public Works Department (Buildings & Roads Branch) was present as a visitor.

His Excellency Sir Harry Haig, K C.S.I., C.I.E., I.C.S, Governor of the United Provinces, who arrived at 11 A.M. was received by the President, Vice-Presidents and members of the Council and conducted to his seat.

In asking His Excellency to open the Congress Rai Bahadur Chhuttan Lal then delivered the following address :—

YOUR EXCELLENCY,

On behalf of the Indian Roads Congress I accord to Your Excellency a most cordial welcome and offer our grateful thanks for coming here to-day, to open the third meeting of the Congress. Before I request Your Excellency to declare the Congress open, I may be permitted to say a few words reviewing its activities from its inception to this day. The necessity of having a technical Roads Association in India was felt by Highway Engineers in India but the idea did not take a concrete shape until 1934 when Mr. Mitchell, the Consulting Engineer to the Government of India (Roads), suggested the creation of a society to promote the interchange of ideas and the pooling of experience in road construction and maintenance. This proposal met with the approval of provincial Governments, and the Government of India with the advice of the Standing Committee for Roads decided to support it and to defray the whole cost of the first meeting from their reserve in the Central Road Fund, so far as official delegates from the Provinces and Indian States were concerned. Without this generous support of the Government of India, the preliminary meeting of the Congress held at Delhi in December 1934 to discuss the proposal and to draw up a constitution for a permanent Congress would have been impossible.

2. The preliminary meeting was opened by the Hon'ble Sir Frank Noyce, Member for Industries and Labour, and the general proposal to constitute an Indian Roads Congress was approved in its broad outline. Papers on earth, tar, bitumenized and concrete roads were read and discussed and a most interesting tour of inspection in Delhi, the Punjab and the North-West Frontier Province was arranged.

The first meeting of the Roads Congress was such an unqualified success that the provincial Governments were unanimous for its continuance and the Government of India decided to finance it from their reserve in the Road Account for a further period of two years.

The second meeting of the Roads Congress was held at Bangalore and the inaugural address was delivered by Sir M. Mirza Ismail, Diwan of Mysore. In this meeting many more subjects such as traffic census, economical maintenance and improvements of macadam roads, use of mollases for treatment of roads, Highway bridges, Research and Experiment were discussed and an extremely instructive tour in Bangalore and Mysore was undertaken and completed

Delegates from the Government of India, provincial Governments, Indian States and business firms attended the meetings of the Congress The subjects discussed ranged widely from earth roads to modern roads of tar, bitumen and cement concrete. Without going into technical details, I give below a brief resume of the discussions.

Earth roads.—The discussion on earth roads resulted in an important proposal for soil research. It was realized that the total length of roads maintained

by public authorities in India (excluding Burma) was about 3,00,000 miles, out of which about 2,20,000 were unmetalled earth roads. Those roads carry the whole of the traffic from the fields, before it reaches the metalled road, the railway or the market. They are, therefore, of vital importance in the economic life of the country and their improvement will play an important part in rural development. But the problem is a difficult one and has, so far, eluded solution. In its technical aspect the problem is partly of soil research and partly of the bullock cart wheel. It is obvious that if a water-bound macadam road fails in three or four years under light bullock cart traffic, an earth road cannot be expected to stand, at all, the strain of that traffic, without a change in the type of the cart wheel. An immediate change on a large scale in the type of the cart wheel which will require less tractive effort and which will be less destructive to earth roads does not appear to be practical politics but there is no doubt that a beginning in this direction can be made by mill and factory owners, by municipalities and Government departments possessing their own thelas and carts. At the same time I admit that it is the universal practice to make the roads to suit the traffic and not *vice versa* but unless this dictum is reversed in the case of earth roads, I see little hope of improving them even in water-bound macadam, as this does not seem to be within the financial resources of provincial Governments. Something might be done by a study of the soils in their relation to earth roads, as it is likely to suggest methods of improvement by blending or other treatment. Experiments with this object in view were carried out in the Punjab and the North-West Frontier Province but the subject is of a specialized nature and requires special study. This Congress has, therefore, resolved to approach the Government of India to provide the necessary funds from their provision for research and experiments in their reserve, in the Central Road Fund.

Next, in extent, to earth roads are the water-bound macadam roads which form and will, in all probability, continue to form a large proportion of the total milage of metalled roads. These roads are suited to carry a slight volume of motor traffic and not too heavy a volume of bullock-cart traffic and the question of increasing their wearing qualities to make them suitable for traffic of greater volume and intensity has engaged the attention of Indian engineers for many years. The greatest difficulty is encountered when there is a mixed traffic of rubber-tyred vehicles and iron-tyred bullock-carts, the latter predominating. The most economical method of improving them is still a disputed point but there is no doubt that surface painting or a covering of a thin carpet of tar or bitumen increases the life of a water-bound road, under certain conditions appreciably. Surface painting, in particular, has been found to be satisfactory and economical under a traffic consisting predominently of lighter rubber-tyred vehicles upto 1000 tons a day. Simplification in methods of construction has been brought about by the introduction of emulsions and cut-backs. Study of the behaviour and structure of grit as well as of the quantity of binding agents such as tar and bitumen have given results which have enabled important improvements in constructions to be effected. Grouted macadam, asphalt or tar concrete, laid by the hot or cold process have also their advocates for heavy or very heavy traffic.

Lastly, I should mention concrete roads which have, during the last few years, been receiving increasing attention, particularly in the United Provinces. Preference is given to cement concrete roads, if the traffic is at all of heavy bullock-carts with iron tyred wheels but economic consideration, especially, the initial cost, plays a large part in selecting the type of road surface to be used. Cement concrete roads are expensive in first cost, if we follow the practice of foreign countries, in which concrete roads of less than 6" thickness are no longer

made. In this Province, a thickness of 3½ inches has been used with complete success so far and the high initial cost has been considerably reduced.

This Roads Congress has given attention to the collection of statistical data relating to the nature and volume of vehicular traffic as they are of prime importance in the classification of roads which is essential to ensure that money is not frittered away by adopting methods of improvement which might be uneconomical. Standard method of taking traffic census and the installations of test tracts and a research station or stations have, therefore, been proposed. This last is an important proposal. Actual tests on roads constructed with different materials in different proportions, and by different methods in various permutations and combinations of climatic conditions, nature, volume and intensity of traffic take many generations and by that time the discovery of new materials and new methods render the results valueless. Test track is a short cut to arrive at results and although owing to the omission of time factor exact results cannot be expected, it is believed that tests carried out under extreme conditions will give safe results.

I have now briefly reviewed the activities of the first two meetings of the Indian Roads Congress. In places, I have expressed my personal opinions also. I need not anticipate the subjects which it will discuss at its meeting, this year. There are subjects which it has not considered so far, such as the width of iron tyres of animal drawn vehicles and their effect on road surfaces, the maximum permissible load to be carried on motor vehicles. It seems to me that the load transmitted by vehicles to the road surface should be such as could be safely borne by the existing bridges and would not necessitate the complete re-construction of our roads or impose an intolerable financial strain on public revenues. So here again we are up against the commonly accepted principle that the roads must be constructed to suit the traffic. It is true that the roads must serve the traffic but the weight and dimensions of vehicles should be restricted, if the equilibrium between the needs of traffic and the resources at the disposal of those responsible for the upkeep of roads, in a good state of repairs is to be established.

Your Excellency, I have taken too much of your time in giving a short account of the two previous meetings of the Indian Roads Congress and in emphasising the importance of some of the problems it has discussed. It is now my pleasant duty to request you to declare this third meeting of the Congress open.

His Excellency then addressed the Congress as follows:—

MR. PRESIDENT AND GENTLEMEN,—

It is my very pleasant duty to welcome you to Lucknow for the third session of the Indian Roads Congress. The choice of Lucknow may I hope be regarded as a compliment to the United Provinces, and on this occasion it is particularly appropriate in that you, Mr. President, have been so long and honourably connected with the Public Works Department of this Province, finishing with four years of valued service of Chief Engineer of the Buildings and Roads Branch. It must, I think, afford satisfaction to you that during your tenure of office steps have been taken to rehabilitate and extend the net-work of important provincial roads, which, owing to the slump in prices and the imperative need for economy, was in some danger of falling seriously, and for an indefinite period, below the minimum requirements of existing traffic. I am sure you will watch future developments with interest, and that, through the medium of this Congress

and otherwise, your friendly advice and suggestions will be available to your successors and to road engineers in general.

As you have pointed out in your address, the important institution whose third meeting we are attending today owes its foundation in no small measure to the energy and initiative of my friend, Mr. K. G. Mitchell, whose presence here today I cordially welcome. He was part-author of that mine of information, the Mitchell-Kirkness report, and he has since had much to do with the inauguration and administration of the Central Road Fund and of the Transport Advisory Council. I think you will agree with me that the Indian Roads Congress is far from being the least important of the many products of his fertile brain.

The whole world over, road policy and transport problems are now being canvassed with a vigour and intensity for which there is no previous parallel: and scarcely a day passes without fresh views on one or other of the many aspects of these problems appearing in the Press. To co-ordinate the various forms of transport so as to serve the public convenience, while reconciling interests which are (perhaps more apparently than actually), in conflict has become a matter of very great importance. But apart from these wider questions of policy the existence of a purely technical body, such as this, concerned with the interchange of ideas on the construction and maintenance of roads and bridges, and with the advancement of road engineering technique, is most valuable, indeed I would say, essential. I am confident that the importance of scientific research in road matters will impress itself in increasing measure on Governments, and that they will find it to their interest to do what ever lies in their power to place this institution on a stable and enduring basis.

Before I pass on to a brief consideration of the main problems now confronting us in road policy, may I, Mr. President, pay a tribute to the lucidity with which these problems and the methods by which they are being met are indicated in your address? It has been remarked, with some truth, that road construction is becoming more and more a matter of the laboratory and of chemical research. I should like to emphasize the need for explaining these investigations and conclusions to the layman, to the taxpayer and to those responsible for the finance and administration of road policy, in terms which they can appreciate and understand. There have been some notable instances in which a popular explanation of technical engineering programmes has evoked a ready response; and, if you wish your technical recommendations carried into practice, I feel sure that you must, in future more than ever before, take the people with you.

What are the main road problems of today? As your President has pointed out very clearly in his address, the long-standing principle, that the roads must be constructed and maintained up to the demands of traffic, is now inevitably called in question by the rapidity with which these demands are increasing. Motor transport asks a great deal of the roads, and we have to consider to what extent by improved methods we can within our financial resources meet the demands, and to what extent it is reasonable to limit the demands, for instance in respect of the weight and the load of motor vehicles. But we must not regard the traffic problem as merely one of motor vehicles. We in this province have witnessed in the last 25 years a very large increase in the number of carts, from some 8 lakhs to about 11 lakhs. Accompanying this increase there is, as our traffic censuses show, an increased use of the roads by carts individually, and especially by heavy iron-tyred carts which are particularly destructive to the road surface. Again, there is the growing problem of

accommodating at one and the same time fast-moving and slow-moving traffic, which raises important questions of the plan of our roads. Fast-moving traffic too has brought in its wake the problem of the dust nuisance, and its discomforts and dangers both to health and to the safety of traffic. Then we are always faced with pressure from the inhabitants of undeveloped tracts for new roads, and for the bridging of unbridged streams. And finally there is the wide field of maintenance and improvement of unmetalled roads and of the extension of village tracks, and the best means of fitting them for the increasing traffic they ought to carry. Without taking into account many more advanced ideas, the solution even of the problems I have indicated seems to demand intensive thought on traffic and maintenance problems, and in the light of present costs a level of capital and recurring outlay which might well make any provincial Government feel despondent.

You will, I trust, forgive me for taking up your time with a mention of some problems which are concerned with general road policy rather than with technical advance in road construction and maintenance. I have done so because the problems which I have instanced all point inevitably to one conclusion, that no great advance is possible without adequate financial resources. It is the paucity of these which make research into road cost and road methods a matter of the most vital importance. If research can evolve metalled and unmetalled surfaces suitable to the types of traffic concerned at materially lower levels of cost than now prevail, then, and only then, is there any prospect of substantial progress. If, for instance, research can evolve a method whereby unmetalled roads can, at the close of the monsoon, when the soil is rapidly hardening, be provided with a cheap but durable surface for the cold weather traffic season, then the gain to the rural public in such matter as delays, the cost of bullocks, and cart upkeep, would be enormous. This gain might very well have the effect of stimulating, indirectly, the extended use of suitably-tyred wheels, and, in particular, of pneumatic tyres. Again, and with reference more particularly to metalled roads, one is inclined to ask whether there is not still a great field for research and experiment directed towards reducing the cost of modern surfacing materials. Again, when signs are discernable of a general economic revival, would it not be of immense advantage if industry could co-operate with provincial Governments to tackle in earnest the production and supply of cartwheels and tyres of cheap but carefully planned design which would save the life both of the roads and of draught cattle?

It is here, gentlemen, that those who have to deal, hampered as they are by inadequate resources, with the vexed problems of road and transport policy turn anxiously, but hopefully, to you and to your deliberations and researches. The Indian Roads Congress is now entering on a stage when, we all hope, it may be possible for technical skill to produce practical results of far-reaching value and importance. It is only very recently that the world celebrated the hundredth anniversary of the death of John Loudon Macadam, the Scottish Engineer whose invention of a method of forming a hard-surfaced road revolutionized the roads of the entire civilised world. Will India produce a second Macadam of her own, to deal with her own peculiar road problems? The need and the hour are ripe.

Gentlemen, I shall not detain you any longer. I thank you for inviting me to attend the opening of your discussions. I have much pleasure in declaring this third meeting of the Congress open; and I wish you all success in your labours and deliberations.

His Excellency then departed and the Congress adjourned till 2 O'clock.

First Day, Monday, February 22, 1937.

The Congress re-assembled at 2 p.m. when the following two papers were read and discussed

Chairman :—Mr. S. G. Stubbs, O.B.E., (Punjab).

Paper No. 32.

SOME NOTES ON THE LAY-OUT OF RURAL AND SUBURBAN ROADS IN THE PUNJAB.

By

R. Trevor Jones, A.M. Inst. C.E., Superintending Engineer, (Roads), and Secretary, Communications Board, Punjab.

Hitherto little attention has been paid to road design in India in so far as it affects the convenience, safety and comfort of the road user and the many and diverse types of vehicles which travel on our highways.

In the Punjab in recent years the immediate need has been the provision of any sort of a road, which can justify the title, from A to B in a spirit of compromise between urgent need and scant means. Even today with a reasonably assured income for development, planning of new roads must perforce be confined to the most modest proportions and standards, if the needs of the Province are to be served as a whole and funds available expended to the best advantage. And no doubt this policy is the correct one even if it postpones the solution of many intricate layout problems to a future age.

Nevertheless the more pressing needs of improvement cannot be thus lightly thrust aside and today many of the facilities which seemed ample to our forefathers now cry aloud for expansion and replanning ; as in years to come our descendents must rebuild and widen the narrow bridge and strait road which is all that can be provided today.

In brief the design and execution of a road to the standard today obtaining in Western countries is an unlikely opportunity for the Indian Engineer—the Indian Road must be a creature of evolution, of slow growth and infinite patience ; a child begotten in haste and reared in poverty : a victim of many vicissitudes and uncertainties.

Widening of metalled widths.—To the uninitiated and shallow observer the width of metalling with which Punjab roads are equipped is a source of wonder and criticism. For the usual width of 9 or 12 feet renders it impossible for two cars to pass each other on the metalled surface and the game of "last off the tar" results in discomfort for one or both parties and not infrequently in disaster. This criticism is readily answered when it is realised that to increase our present road widths to 16 feet (which is the minimum width in which two vehicles can pass each other) will cost approximately 2 crores of rupees, if the same standard of metalling as exists is observed. Already urgent road widening has reached a figure of 5 lakhs of rupees and it will be many years before

two-way carriage roads are established throughout the Punjab. Certain stretches of roads, such as the first 17 miles of the Rawalpindi-Murree-Kashmir Road, are at least 18 feet, whilst the Lahore-Amritsar Road is 20 feet minimum in width. At the moment the criteria, which will establish the crucial state of affaire where further increase of the metalled surface is vital, is a question which is exercising engineers' mind in the Province. At one time it was felt that the main need was to distribute the weight on heavily trafficked roads over a wider surface; but it is now realised that it is the safety of the public and the avoidance of accidents which is the main object. It has been suggested that at certain selected points in the busiest thoroughfares, observations should be made of the number of times vehicles are forced off the direct metalled surface on to the berms and observations thus recorded of the comprative use of berm to central strip. It is also being considered whether it will not be possible to widen roads to a cheaper specification by the uso of brick ballast or kunker to suitable thickness subsequently tarred. If this would not result in a particularly stable road, it would at least provide a hard surface in place of the doubtful and skid-causing earthen berms.

The need for improved berms.—However it is realised that to widen the metalled roads universally throughout the Province under present economic and other conditions is prohibitive, and efforts must be made to improve berms. The long established methods of making up berms to the level of metalled surface after consolidation or tarring are too well-known to be described here. The state of earthen berms naturally depends largely on the soil in the vicinity, but more frequently it is climatic and seasonal conditions that provide either that the berms shall be loose dust or liquid mud. Under such conditions it is usually the case that the earthen berm has worn away from the metalled surface, leaving a considerable drop between the two. Therefore it is necessary that far more attention should be paid to the maintenance of berms if they are to be used with greater safety by fast moving traffic than obtains at present. The difficulty is of course that radical improvement must make for expense and increased maintenance cost, but still there are ways and means and a good deal of indigenous material which could be successfully used for roughly metalling berms. Hitherto in a great many places good clay earth has been imported at considerable expense to maintain the berms as it was considered a breach of fundamental rules to employ anything else.

Rough metalling.—In Rawalpindi District a great deal was done by the writer in roughly metalling the berms with conglomerate sand stone or boulders, which can be found lying about in most parts of the Northern districts. This stone crushes very easily and is not of much value for consolidation owing to its shape. The method employed in Rawalpindi was to hand pack the sides with boulders and a certain amount of earth mixed with them, thus forming a pavement which was consolidated partially by traffic and occasionally by steam road rollers. Orders were given to road roller drivers to keep their eyes open when moving from place to place and not to travel in the centre of the road but on the sides in order to consolidate the berms. If a berm could be consolidated prior to the application of a tar paint coat the surplus bajri or shingle would be spread over the sides and a very satisfactory joint between the berm and macadam would result. However the rapid run off of rain water usually formed a channel between macadam and the berm pavement and thus the drop between the metalled surface and the berms was not entirely eliminated. The cost of such rough metalling was approximately on an average Rs. 40/- % cft. including consolidation. This is about twice the cost of imported earth for berms but as its life was 2 or 3 years and earth filling for berms is an annual event, it is an economical

process. During the writer's time at Rawalpindi it was gratifying to note that frequently bullock-carts appeared to prefer the berm pavement to the tarred road. Again where river shingle is within reach, good results can be obtained by spreading it loose in the form of a gravelled path over the consolidated earth of the berm. However, such intances of the availability of cheap shingle are rare.

Brick edging.—A method which has not been adopted to any great extent in the Punjab but which appears to be used considerably in the Delhi Province is to place a brick on edge curb at the edge of metalling. Such a protection would go under the category of original works and would cost Rs. 700/- a mile, but it appears to be very lasting and eliminates to some extent the danger of a drop between metalling and the berms. In most old established roads a great deal can be done by the collection of spare metal, brick ballast, etc , and forming a "pashta" of about a foot at the edge of the tar As a temporary measure this was fairly successful but supplies of "treasure trove" in the form of spare metal soon became exhausted. A great deal more might be made of kunker deposits, if they occur close to the road, by spreading this material a few inches thick over a well compacted berm.

Earth stabilization.—Recently in the Gurgaon Division on mile 19 of the Delhi-Alwar Road an experiment was tried with the use of "Bitumuls" as a stabilizer to the earth of the berm. The soil was stabilized with a 2" mat with 3% bitumen content, which worked out at Rs. 3/-% sft. When it is realised that a coat of 3" brick ballast could be laid for about Rs. 2/-% sft. the use of bitumen as a stabilizer does not appear to be a very economical proposition.

Watering berms.—Of course where canal water is available or where water can be pumped on to the berms, very valuable results can be achieved ; in fact it may be that the easiest and the least expensive solution of the earthen berms question is a systematic organization of watering periods In sandy soils attempts have been made to meet the situation by the use of grass mats made from reeds, surkanda and scrub but all these methods are merely palliatives and are not really satisfactory.

In canal areas water for kacha roads is available at Rs. 30 - per mile per annum for 8 waterings except in October and November : but supplies are by no means assured. Also if and when the soil physicist and the engineer in combination produce practical means of stabilizing earth to withstand traffic without breaking up, obviously a great improvement to berms will be possible and safety to the travelling public will be increased. However safety cannot be assured until at least 18 feet of uniformly compacted fairway is provided—an ideal impossible of realisation at the moment.

Dual Carriageways.—The Consulting Engineer to the Government of India (Roads) has recently propounded an interesting idea that in cases of existing water bound roads, which require reconditioning and on which heavy bullock-cart traffic move, whether it would not be advisable to surrender the existing road to the carts and to construct alongside an entirely new track, which would be reserved solely for fast moving vehicles. The conditions necessary for the fulfilment of such an experiment were (i) that the road formation should be at least 50 feet and (ii) that the avenues of trees should be well away from the road. As far as the Punjab is concerned, unfortunately or fortunately the majority of heavily trafficked roads are tarred and no saving, and in fact much greater expenditure, would result in the construction of new tracks for any particular

form of traffic. However it is possible that experiments of this nature may be tried out in parts of the Province where kunker is cheap and readily available. It is believed that if the bullock-cart can be excluded, it is possible to tar directly on to the kunker surface, and very considerable economies would result thereby. What perhaps is more interesting in this suggestion is the dawning conviction that segregation of various sorts of traffic is becoming of vital necessity and is perhaps even more urgent in India than in Europe. Dual roads and special tracks for various categories of traffic are becoming more and more established in England and it is obvious that sooner or later something will have to be done on the same lines in India, with its motely road population of vehicles of varying speeds and controlability. Segregation of traffic however is by no means unknown to India and it would appear that in the early days when the Grand Trunk Road was laid out, the wide road lands acquired were meant to accommodate many sorts of traffic on seperate tracks. On a page in Kipling's Kim will be found the following passage :—

> "And now we come to the Big Road.........the Great Road which is the backbone of all Hind. . For the most part it is shaded as above with 4 lines of trees: the middle road—all hard—takes the quick traffic. In the days before rail-carriages the Sahibs travelled up and down here in hundreds. Now there are only country carts and such like. Left and right is the rougher road for the heavy carts—grain and cotton, bhossa, lime and hides."

There would thus seem to be a presumption of truth that in the early days segregation of traffic was a normal condition. Today the sidetracks i. e., "rougher roads", in many cases have entirely disappeared and the roadland away from the formation is an area of borrowpits, dumps for road material, arboricultural activity and not infrequently the happy hunting ground of the encroacher. Consequently today an area of formation of some 30 feet is the only real highway and is used by all and sundry. From the motorist's point of view it would be the greatest advantage if it were possible to forbid the bullock carts and the slow moving unwieldy vehicles the use of metalled road altogether: but the latter vehicle appears to have established its right to the metalled surface and undoubtedly the hard surfaced road enables the Zamindar to carry far heavier loads with less tractive effect than on the katcha road. Nevertheless sooner or later sidetracks must be provided for the slow moving traffic on established routes even if the cost appears prohibitive at the moment.

An example of lay-out for traffic segregation in Lahore.—An example of an almost ideal road in this respect can be seen on the section between the Chota Ravi Bridge and the approach to the main Ravi Bridge at Lahore. Here on either side exist special tracks for heavy bullock carts, which are habitually used by them. It is true that one track on the west side of the formation is metalled but on the east side it is katcha and appears to be as impartially used as the other side. This section of road is also very interesting as an example of the wear and tear which the heavy bullock carts exercise on a tarred water bound road. For at the moment the segregated section possesses a smooth uniform surface, whereas the adjoining sections used by bullock carts is definitely the reverse. (See photographs at the end of the Paper).

In the layout of the new arterial roads in the Province it is unfortunate that means do not allow for the purchase of land to the old minimum of 110 feet. The Grand Trunk Road is in many places 150 feet and over. This at least provided additional land for future sidetracks. The tendency today is to

meet the onslaughts of bullock carts when the intensity is excessive, by provision of concrete trackways. This meets the situation from the material sense of weight of traffic but does not solve the question of safety of the public. It is not the intention here to press for universal provision of special roads for bullock carts and slow moving traffic as such an ideal under the present circumstances is obviously incapable of realisation. However it would seem wise to maintain side tracks for the use of pedestrians, mules, horsemen and unladen bullock-carts etc. on either side of the main formation and at least to make them passable for the passage of such traffic away from the crowded metalled thoroughfares. Hitherto the Public Works Department and local bodies have not been encouraging the use of the additional land for such purposes, and to the writer's mind there is nothing more aggravating to find than both sides of the formation fenced of for miles for the purposes of arboricultural plantation and nurseries and any means of escaping from a stream of lorries, cars and other vehicles denied to the humble pedestrian or venturesome equestrian.

Modern Practice in Europe.—It is interesting to note the acceptance of the principle of segregation of traffic of various kinds in present day planning. A typical section of a new road is reproduced in plate No. I. Special cycle tracks are a feature. It will be seen that no provision exists for the domestic animal in any form and it is presumed that unless conveyed in vehicles the presence of such traffic is not contemplated on this road. Although it has been said earlier in this paper that the Indian Engineer cannot hope to design and build roads to the standard of Western countries yet he is not debarred from building "Castle in the air" like anyone else.

A section (see plate No. II) is attached which is an adaptation to suit Punjab (and North Indian) needs of the English prototype. Athough such a lay-out may be today considered lavish and extravagant to a degree, it is obvious that if motor traffic increases some such replanning will be inevitable on many of our trunk roads.

Roadside trees.—In the layout of roads in India the planting of trees is an integral part. In the Punjab a Divisional Forest Officer has been recently appointed to examine and co-ordinate arboricultural activities in the Province. The appointment of this officer has put rather a new complexion on the question of roadside arboriculture and to some extent there has been a clash of ideals. The road Engineer feels that the main reason of tree planting is to provide shade; with the Forest Officer the commercial aspect looms large. It was recently pointed out that roadside arboriculture was not a paying proposition and that the expenditure was Rs. 1,50,000/- and the income Rs. 32,000/- on an average for the last five years. From this point of view the error of the P.W.D. officer has been in his failure to fell trees which are most valuable for commercial exploitation. The P.W.D. officer, with perhaps an eye to the æsthetic side, has not the heart to fell roadside avenues in their prime ; in fact he would probably get into serious trouble if he did. The tendency then exists to remove a tree only when it obstructs road or fairway or is unsightly owing to decease. On Punjab roads therefore the day of reckoning has arrived and the Province is faced with the verdict of the expert Forest Officer who advises the wholesale removal of magnificent avenues of trees as they have reached already their prime and will be soon of no value as timber. It is true that three new trees are planted for every one felled but as this is a reparation for the future it is hard to convince the Road Engineer of its immediate necessity. No doubt the problem will be solved in a spirit of compromise. But in laying out and planning new roads it is patent that the advice and co-operation of expert arboriculturist

as to the type of tree to be planted is most valuable and a very obvious form of co-operation between departments of State. The criticism might be levelled at present methods that too many trees are planted on either side of the road and the idea of avenues is frequently lost. The main ideal would appear to be that trees are planted at the edge of formation and at boundaries. Another point for serious consideration is the position of the formation edge trees. In many cases on the older roads trees were planted frequently on the slope or the toe of berms and trees in such position have undoubtedly been the cause of death and injury on the roads in recent years: true due more often than not to careless driving. At present it is proposed to plant no trees nearer than 25 feet from the centre of the road. This is all too close and if and when road formations have to be widened wholesale felling will be necessary. In fact it is for serious consideration whether trees at the toe of formation should not be abolished altogether. It is arguable whether fast traffic need shade trees at all and that if special tracks are made and used by slow traffic, whether arboricultural activity should not be confined to the latter's amelioration. There is also the question of the advantages of shade to the life of the tar or bitumen employed as the surfacing medium. Protection from the sun's heat undoubtedly obviates bleeding in the case of tar and prolongs its use.

However custom and present traffic conditions demand that the edges of road formation shall be fringed with trees and if and when something of the nature of road planning adumbrated at page 14 materialises, such trees as are now planted will be cut down and sold to the joy of the commercially minded Forest Officer.

Poles on roads.—Another feature of modern roads which requires forethought and design is the position of posts and pylons carrying cables, telegraph and electric power; most of which have to be accommodated on important roads. In and outside many big towns the haphazard methods in which lines of cables, their posts and stays, have been situated are a considerable cause of embarrassment and expense at the present time. With road improvements, widening, footpaths etc., which are inevitable in these days, constant shifting of lines is rendered necessary and it is patent that some considered plan of original layout for such services must be included in original planning. To lay down standards for future planning is not easy owing to the diverse conditions which must arise but it all goes to prove that land additional to the formation width is necessary and that such extra land must be carefully parcelled out to provide for

(1) trees,

(2) side-tracks,

(3) electric light and telegraph poles,

(4) paths,

(5) borrow-pits and dumping grounds.

The term 'road *waste* land' should be sternly suppressed as it is the foundation of many misconceptions.

Hill Roads, Corners and Curves.—In the Punjab there are a considerable number of hill motor roads but none of them were designed originally for motor traffic, although the new Programme provides for the construction and improvement of a number of such roads, especially in the Salt Range. In recent

years considerable sums have been spent on improving curves and corners. Lately on the Kalka-Simla, Rawalpindi-Murree and Amritsar-Baijnath for example, considerable sums have been spent on widening corners and segregating up and down traffic by the provision of white studs in the centre of the road. On the Kalka-Simla Road 350 such corners have been established and everywhere two carriageways of a width of 10 feet each provided. In laying out curves on roads generally, particularly hill roads, it is not only necessary to pay regard to super-elevation but to suitable widening of the road at curves. The South African National Road Board has laid down recently very interesting standards among which appear a formula for increasing formation widths at curves which is as follows:—

"On curves all formation widths and gravel (metalled) widths are to be increased by $\frac{1,000}{\text{Radius in ft.}}$ feet, this widening to be effected on the inside of the curves. The transition shall be effected over a length of 150 feet, half on the straight and half on the curve by means of a circular or parabolic curve joining the inside edges of widened and unwidened sections." The problem of adopting existing hill roads to motor traffic to render them reasonably safe is most formidable as the expenditure involved to attain a reasonable standard of curve, grade and width is immense. Many hill roads in the Punjab are being used by motor lorries and cars which are frankly dangerous and the accidents which have occurred are of unusual severity.

Roundabouts.—Last year the intensity of motor traffic on the Mall at Lahore necessitated the trial of roundabout system. The actual form and shape has been the subject of a good deal of discussion between the Police and the Public Works Department. The system of roundabouts has been more or less established in England and other Western countries but the principles of design are by no means standardized. The roundabout near G.P.O. at Lahore is an interesting example of a number of minor roads joining a major thoroughfare. On the major thoroughfare (the Mall) bullock carts and slow moving traffic are not permitted but this is not the case on the subsidiary roads. Consequently conditions are difficult for fast moving traffic on the major road (the Mall) which is frequently held up by the passage of bullock carts etc. moving around the roundabout. Further there is a tendency for cars moving along the minor roads to get across the Mall at great speed if the way is clear and thus hold up the main stream. The following notes on design of roundabout to meet the conditions described, taken from a paper from Colonel Blackwell, County Surveyor of Leicestershire, and published in the *Highway Engineer* (for May 1936) are of interest and may be that the staggered approach as proposed therein for minor roads may meet situations as exemplified by the G.P.O. crossing at Lahore:—

"Where a bridge or light signals are considered unnecessary or undesirable, a roundabout is likely to meet the case.

"An island, usually circular and with a diameter of at least 80 feet is sited in the centre of each road, the circular road being of such a width and the radius of the curves at the junctions of the circular and radiating roads being such as to insure correct retardation of vehicles for the sake of general safety.

"Twenty feet is a usual width for the circular road and thirty feet the radius at the external angles.

"The forty foot radius of the island has been found most suitable for all vehicles, including those with the longest wheelbase.

"Thirty foot radius has been found necessary to obtain the required retardation. In the case of all intersections and juctions on the level it is necessary to insure retardation, although this is a serious reduction in the efficiency of each road as a means of transport which should be designed to provide for maximum speed, carrying capacity, safety and comfort with minimum distance and ourvature, horizontal and vertical.

"This need for retardation is often not appreciated by drivers who sometimes point out that an intersection or junction could be designed to allow of greater ease and speed—a defeating of the object of the design, namely retardation.

"Some members will be aware that when such drivers happen to be also members of the responsible highway anthority, the position of the engineer, also responsible, is rendered difficult, and firmness in insisting on correct design is necessary.

"Turning to the intersection of roads carrying distinctly unequal amounts of traffio, the staggered crossing has been found effective whereby fast, through traffic is not checked, but traffic on the minor road is compelled to slow down or stop till a safe opportunity occurs to weave into the traffic on the major road and out of it again, by a rightangled, left-handed turn in, and a rightangled, right-handed turn out. Here again a radius of 30 feet should be provided at the angles."

However it would appear that again the bullock cart is the 'devil among the bakers.' The occidental designer of roundabouts has not this vehicle to contend with and it would appear that a procession of bullock carts traversing a roundabout could cause the most widespread traffic dislocation.

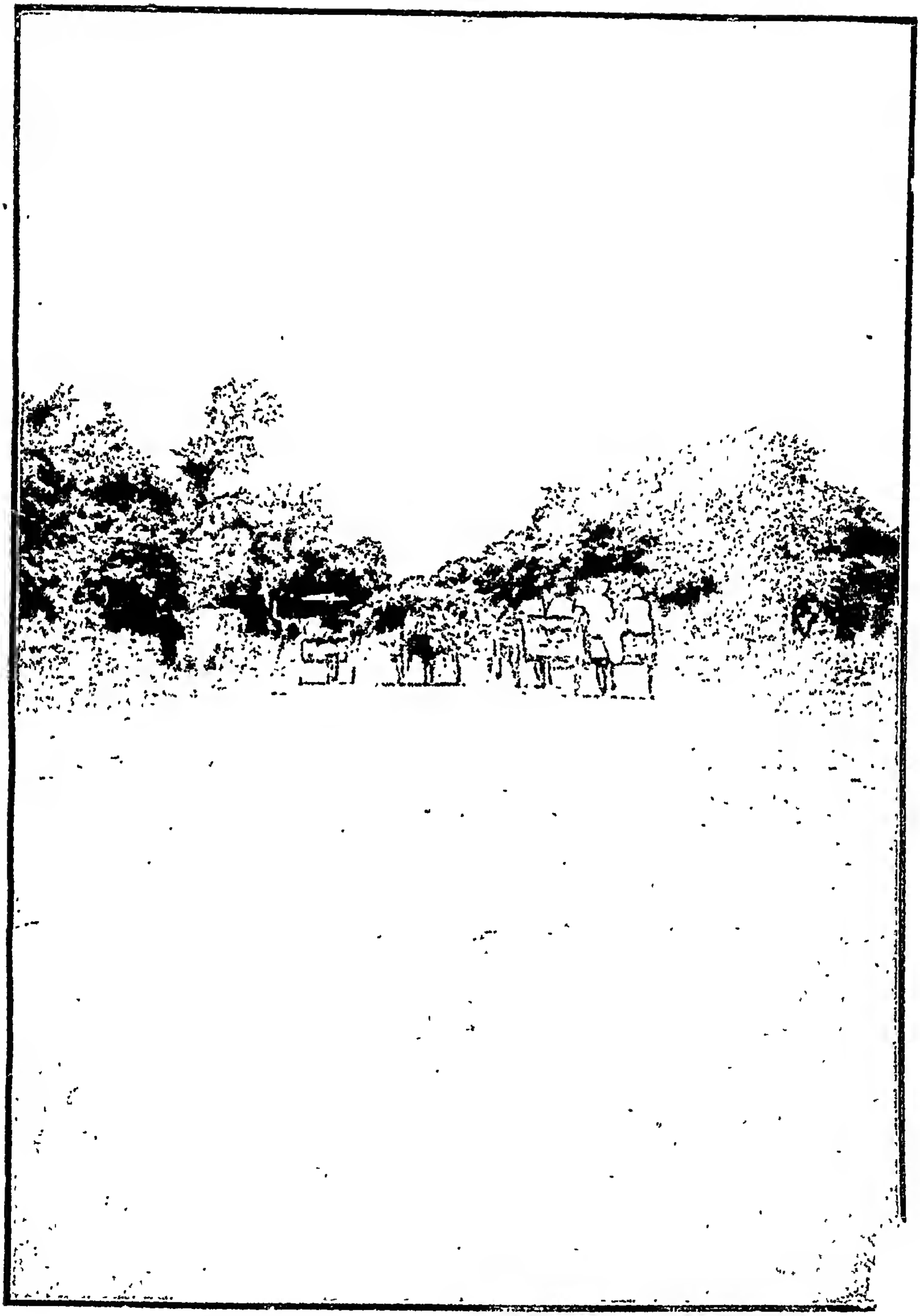
Conclusion.—Quite apart from questiou of railway competition, Governments do not like roads. They are an expense, with no assessable return.

But the public of India are undoubtedly each year becoming more road-minded and it is fair to assume that this need will express itself in a forceful demand for safe and adequate roads "Where there's a will there's a way"—the means will be found to create and plan suitable highways and it is the writer's plea that whilst fulfilling the immediate task with the means at our disposal, the ideal of something better than the present best should not be put away as beyond our ken.

Roundabout facing the G. P. O. Lahore Mall.

Road enclosed on either side by fenced-in plantations making, [illegible] available for traffic.

To illustrate road formation enclosed on either side by forced-in tro



To illustrate use of berms and obstruction to fast traffic by lack of "Road sense."

DISCUSSIONS ON PAPER No. 32.

Mr. R. Trevor Jones (Author):—Mr. Chairman and gentlemen,—I must commence by apologising for the somewhat superficial and sketchy nature of my paper.

The lay-out of roads is a big subject to tackle and one which has become a prominent issue in recent years. Road design must perforce be a matter of evolution rather than the result of critical scientific investigation. If it were the latter, modification would not be so frequently necessary. Further, funds are scarce and it is only possible to achieve the minimum results. In contra distinction to Irrigation and Railway works, it is seldom possible to design a road project to any degree of finality as a comprehensive scheme. Nevertheless in designing new roads the fact that expansion will sooner or later be a vital necessity must not be lost sight of and scope or "elbow room" be retained to meet the demands of the future. In my paper I have attempted to show the present position in the Punjab. I would say the greatest needs on our metalled roads today are :—

(i) provision of two carriageways ; and

(ii) segregation of slow and fast traffic.

I have made it clear that such improvement is not financially possible immediately, but my plea is that a great deal more can be done at moderate cost to improve things. We cannot provide two carriageways ; so we must pay far more attention to our berms and we can pave the way for segregation of traffic by making and maintaining side tracks and induce the habit of their use by carts, animals and pedestrians. Further the future must be provided for by acquiring sufficient width of land in all new roads at the outset. At page 13 I refer to certain photographs of the bullock-cart road in Lahore but these have unfortunately been omitted by the Roads Congress Powers that be. I however have them with me should anyone wish to see them.

Mr. S. Bashiram (Punjab) :—Mr. Chairman and gentlemen,—I wish to congratulate Mr. Trevor Jones on the excellence of his paper. It may be as he says, sketchy, but it is most useful. There are just a few points that I wish to comment on.

On page 12 of the paper Mr. Trevor Jones has made some remarks about brick edging. I am afraid I do not agree with this idea of giving an edge in bricks or any other material like that. This brick edging or curb only removes the mischief some 9 inches away and the objection still remains. Those of you who have driven along the Delhi-Ambala Road must have seen that this curb exists on the road in Delhi Province, and that the bricks are standing there sheer proud, a matter of two or two and a half inches, and every careful driver avoids them. Further, the surface presented by these bricks is extraordinarily rough and I really do not see any advantage at all in having them.

Then there is the question of earth stabilization. The experiments which Mr. Trevor Jones refers to were actually carried out in one of my divisions, and however excellent this stabilization may be for aviation grounds and similar requirements, I am certain that it is not any good for road berms, as the stabilized earth mat crushes very badly indeed under bullock-cart traffic. Apart from this there is of course the question of expense. It is not economical as we find that a coat of three-inch brick ballast is definitely cheaper and more satisfactory.

Then on the same page, Mr. Trevor Jones discusses the question of dual carriageways. The cheaper [illegible] sition in the Punjab where all Provincial roads [illegible] propo [illegible]

have been tarred, would appear to be to reserve existing surfaces for the fast traffic and to build entirely new surfaces for heavy bullock-cart traffic which need not be tarred at all. As a matter of fact the estimate for a trial length that we have sent up to the Road Engineer for being funded has been drawn up on these lines.

At page 15 there is the mention of hill roads. Observations on the Kalka-Simla Road show that the width of the carriageway round curves should be a minimum of 11 feet, if not 12.

At page 17 in the "Conclusion" Mr. Trevor Jones says, " Quite apart from the question of railway competition, Governments do not like roads. They are an expense, with no assessable return ". That possibly may give a wrong impression, because from what I know of Mr. Trevor Jones's views I do not think he subscribes to that statement as it reads. I think he is definitely of the opinion that roads are not a luxury but a necessity and that the return on expenditure incurred on them is definitely a profitable one. A very simple calculation will show you the fallacy underlying the erroneous belief he refers to. You will find that if a bullock-cart carries a one and half ton pay load and the saving in freight due to metalling an unmetalled road amounts to one pice per maund per mile ; and ten bullock-carts use that road, the total saving in freight will not only pay for all the maintenance charges but actually the interest on the capital involved in metalling the road.

Mr. K. G. Mitchell:—I would like, Mr. Chairman, as Mr. Bashiram has done, to congratulate Mr. Trevor Jones on raising a question which is going to become more and more important as time goes on. He is however somewhat pessimistic about what can be done. He comes, of course, from a province where they have made a good deal of progress in adapting roads to modern conditions and perhaps find it more difficult to turn back and start on new lines than it would be elsewhere. There are one or two points on which I should like to join issue with Mr. Trevor Jones. For instance, he refers on page 10 to the road system of India as "a child begotten in haste and reared in poverty". He then, if I may say so, contradicts himself at page 13 by saying, "There would thus seem to be a presumption of truth that in the early days segregation of traffic was a normal condition". They are rather contradictory statements. I think that as a matter of fact the fault really lies with the present generation, that is to say, with ourselves. The Grand Trunk Road in many places, he says, is 150 feet and more wide. I think that in many places it was laid out originally even wider, and undoubtedly it provided room for segregation of traffic without hurting anybody. But that heritage of the past which was provided by our forerunners with considerable forethought has been, to my mind, destroyed by apathy on our part in not preserving the original lay-out and by even greater apathy in allowing haphazard borrow pits to be dug all over the place, so that all that space is rendered useless at present.

I personally entirely agree with Mr. Bashiram that edging with bricks is of very little use. You want edging on any material which is liable to push under traffic; but I cannot see that it is necessary to edge painted water-bound macadam or that it is much use edging a hard surface with brick which is softer. Brick is no good for anything which requires real lateral support. It has, moreover, the disadvantage, that, roughly speaking, you cannot roll it without destroying it. The proof of the pudding is in the eating. I think that between Delhi and Lahore the places where there is the most pronounced drop between the edge of the metalling and the berms is in the province where there brick edging is used. It is to my mind dangerous and serves no useful purpose.

As regards earth stabilization, I should say that generally the improvement of berms offers a more hopeful field for stabilization of soil than mere earth roads which are subjected to heavy bullock-cart traffic continuously. I quite agree with Mr. Bashiram that the types of stabilization referred to in the paper which have no recuperative value are of very little use; that is to say, if you stabilize with some bituminous emulsion, you would be stabilizing the soil only for a time. Once it is cut up it has no recuperative value. You will have noticed, particularly in the Punjab, Sind, and I think in the United Provinces, certain conditions of soil where the berms are very much better than elsewhere, and I believe that it is due to alkalinity in the soil. I think that by studying the chemistry of these soils and endeavouring to reproduce it elsewhere artificially you may get some improvement of berms—an improvement which gives them recuperative value; that is to say, with that composition of soil you can at any time when it is moist reform it, roll it or do whatever you like with it, and it will set up again.

At page 14 Mr. Trevor Jones says, "It would seem wise to maintain side tracks for the use of pedestrians, mules, horsemen and unladen bullock-carts, etc., on either side of the main formation". I entirely agree. But unfortunately the land has been so cut up with borrow pits etc., that it is now a matter of considerable expenditure to restore it.

In the Punjab where you are planting triple avenues without first levelling the land you are making it more difficult in future to restore that land to some use. Everybody knows that nobody travels on the carriageway, on the road which carries fast traffic—I mean, no pedestrian, no person riding a horse, will voluntarily travel on the carriageway if he can get away from it and motor traffic. Where you have got this extra width I think a great deal of improvement could be effected by levelling it and bringing it into use. Of course, you will have difficulty at bridges and culverts where sometimes the traffic will have to come back to the carriageway; but there are ways of making cheap culverts for very light traffic of the sort.

There is one other point. Mr. Trevor Jones said that a good deal of obstruction is caused by the fencing for afforestation purposes. I would say that this is only a temporary effect which will last for two or three years, and that the permanent value of afforestation by that method is great. But in the plains where there is plenty of room you should not, in my opinion, in any new planting plant your trees nearer than 65 feet across the road. Mr. Trevor Jones says that 50 feet is enough. But if you work it out with reasonable slopes for berms you will find that 65 feet in a few years time will not leave too much room. That is my opinion. I asked an artist friend of mine to draw a coloured poster of my conceptions of the future main roads in India showing what I have been trying to describe—a way for pedestrians, a carriageway in the middle and so forth, but I regret that he has not done it for me yet, so I cannot show it to you.

If I may take a little more of your time, there is one other thing to which I would like to refer, and on which I feel very strongly, and that is that the railway type of embankment still prevails unnecessarily in road construction. Banks are often too high merely because someone in the drawing office thinks it looks pretty to use a long straight edge to mark the word formation on the longitudinal section and to have many chains at a uniform gradient painfully worked out and written in as, say, 1 in 106.34. The result is that at intermediate points you have a wholly unnecessarily high bank which is a waste of money in center work and a nuisance in perpetuity. Having reduced formation

level to the minimum necessary there is no earthly reason why you should economise a few cubic feet of earth by giving the little bank steep 1 to 1 side slopes which are expensive to maintain. If you run your berms into your side drains at a reasonable slope you can often increase the capacity of the road by 50 per cent and reduce the cost of maintenance of bank edges for an increase in the cost of earthwork of say 2 per cent.

And lastly, Mr. Trevor Jones alludes to the possibility of a dual carriage-way. This does not perhaps appeal so much in the Punjab where all the main roads have been tarred. If you have got a 12 feet metalled road which is unable to carry the present day mixed traffic, the present idea is gradually to widen it and to give it some superior surface which will carry both classes of traffic, and with the exception of cement concrete we do not know of any surface intrinsically suited to both types. We know that many surfaces suitable for motor traffic are liable to be damaged by bullock-carts. It is a matter for investigation and experiment whether it is not possible, for the same cost of maintenance, to leave our metalled roads for bullock-carts as before and to provide a separate comparatively cheap road for the fast motor traffic. Then you will have roads adapted to the traffic which may use them. It is a matter for investigation and experiment; but it seems to me arguable that ultimately your maintenance cost, which is what matters, will not be very much greater, and possibly will be less, if you have two road ways aggregating 20 to 24 feet than it would be for a 20 feet road used by both classes of traffic. This is a suitable subject for experiment.

Mr. R. L. Sondhi (Punjab):—Most of the suggestions in Mr. Trevor Jones's paper will, I am certain, in due course be adopted on the arterial roads all over the country. Some of these may have to be deferred on account of financial difficulties. Those of you who are present here will agree that this paper is a very useful contribution and will help in carrying out road improvements in different localities. Some of the improvements suggested may be difficult to carry out due to financial difficulties, but there is one which Mr. Trevor Jones has recommended—the need for improved berms—on page 11 to which I should like to refer.

Mr. Bashiram has already suggested that the way of doing this by stabilizing with some sort of material of the nature of oils or other things which have been recommended for stabilizing earth roads may not be suitable. And I also think that the cost involved will be high. I believe that in the case of the experiment tried at Gurgaon the cost worked out to more than that of laying brick ballast.

Mr. S. Bashiram:—That is why I did not recommend it.

Mr. R. L. Sondhi:—I am sorry. Mr. Mitchell has suggested that we may have some sort of road on the berm which may be more suitable for motor traffic and leave the existing water-bound metalled surface for carts. That again will involve so much expenditure that due to financial consideration it will take a long time before we can adopt it. Probably the best way is to improve our berms which generally are in bad condition and cause a lot of accidents. I do not think in India we have statistics regularly tabulated as in foreign countries, but most of the accidents are due to the level of the berms which are generally in deteriorated condition. I have personal experience of having worked out this scheme of Mr. Trevor Jones, as a Sub-Divisional Officer at Jhelum, where we have lot of stone lying idle and I think I was able to improve quite a long stretch of road leading from Jhelum to Rawalpindi. That

scheme, I can assure you, was a very successful scheme. I do not know whether it has been followed since I left. Similar materials, I mean to say, even broken pots from the villages or anything which the ingenuity of the man in charge can think of can be used.

I have only a few words to say about roundabouts. At page 16 Mr. Trevor Jones says, "The actual form and shape has been the subject of a good deal of discussion between the Police and the Public Works Department". But I am afraid an important party to the compromise was left out of consultation: I mean the tongawalas, and when I make this complaint here, I do so on the testimony of one of them who has complained that his horse had slipped as a result of the elliptical design. I was told that the curve at the General Post Office is too sharp for horse traffic to negotiate and I hope an effort will be made to get this point investigated, as, taking into consideration the number and actual tonnage, the tongas contribute the largest number of vehicles using this particular crossing.

Mr. P. L. Bowers (Jaipur):—I should like to endorse one remark made by Mr. Mitchell and that is regarding the treatment of side berms where the roads are in low bank. In Jaipur, most of our road formation is very little above the natural ground level, but where banks are necessary the sides are not dressed to any given slope but run them off into the drains. Another point which I should like to emphasise is that more attention should be paid to the berms. In Jaipur, except where these are sandy it, is safe to run off the metalled surfaces of our roads on to the berms at speeds of from 40 to 50 miles an hour and this is due to the fact that we keep permanent gangs at work continually dressing the berms.

I quite agree with what Mr. Mitchell has said about road side trees. I think that generally speaking trees are planted far too close to the centre of the road, especially where road surfaces are of water bound macadam. The presence of the trees close to the roads prevents dust raised by motor traffic being dispersed by the wind and on still evenings, when the light is falling—which is the most dangerous time for motor driving—it is frequently impossible to follow another car at an interval of less than a mile without taking considerable risk. I am also of the opinion that greater space between trees along the line of the road than is at present allowed is necessary and to facilitate the disposal of the dust they should be at least from 80 to 100 feet apart and 65 feet across the centre of the road.

As regards earth roads, I understand that in America experiments have been made with certain salts which retain moisture in the soil and have the effect of making the soil similar to Kalar earth. I do not know whether the Road Congress has any information on this point, but I believe that experiments with salts have been made both in Sind and in parts of the Punjab and I would enquire whether any information on this point could be obtained.

Mr. N. Dass Gupta:—Chairman and Gentlemen: I welcome the suggestion of Mr. Trevor Jones of improving the berms and agree with him that clay berms are definitely dangerous especially during the monsoon. This is due to the fact that when two cars pass, one wheel of each car travels on the clay berm and the clay is thus carried on the smooth and wet asphalt or tarred road making it unusually slippery. In all places cheap materials such as broken bricks, kankar or rubbish from demolished buildings may be obtained which may be spread along the road for a width of 2 feet on either side and consolidated by a hand roller. Subsequently the

berm may be given a light surface treatment with a cutback asphalt and sand or cinders. The cost of widening at the rate of Rs. 2/- per hundred square feet as given by Mr. Trevor Jones comes to about Rs. 450/- per mile. The cost of giving a light surface treatment will be about Rs. 350/- per mile. Thus at a total cost of about Rs. 800/- only, we can get a 16 feet wide road out of a 12 feet wide road. So there is no reason why such methods should not be adopted.

Mr. E. A. Nadirshah (Bombay) :—I agree with Author when he says that little attention is paid to road design in India in so far as it affects the convenience, safety and comfort of the road-user. I go a step further and say that road design must be such as to reduce maintenance costs, which object could be achieved if

(1) short radius horizontal curves are avoided ;

(2) adequate super-elevation is provided :

(3) at corners grade and vertical curves are made easy for traction particularly in regions of high altitude remembering that an average combustion engine loses about 3 per cent efficiency for each 1000 feet of altitude. If it is too expensive to cut down the grade, the question of widening the road may be considered *i.e.*, addition of a traffic lane for slow traffic ;

(4) that short sight-distances are eliminated and ample visibility is provided ;

(5) proper right of way is provided ;

(6) adequate intercepting and surface drainage are provided ; and

(7) nonskid surfaces are constructed by avoiding excess of cementing material on top.

If we do not look into these points at the time of building a road a time will soon come when due to increase in number and speed of vehicles, we will have to stop building new milage to improve the existing milage.

Widening of metalled widths.—Sixteen feet carriageway for two lane traffic may be considered on the narrow side as when vehicles pass each other in this narrow strip the outer tyres get off the pavement particularly where bus traffic is heavy or vehicles are fitted with dual tyres. This narrow width is not only dangerous to passing vehicles but it entails much additional cost in maintaining the Katcha berms. So it is a question for consideration whether it would not be worth our while to increase the paved width say to 22 feet or at least 20 feet as the extra cost in paving this additional width may to a certain extent be compensated by lower maintenance cost of berms. It would also be advisable to fix a standard width for different lanes of traffic for the whole of India to preserve uniformity.

If river shingle is spread loose in the form of a gravelled path as suggested by the Author, I am afraid it would increase the risk of skidding of cars as there is bound to be some turning movement when cars go off and come back to pavement in a short distance while overtaking a car on the paved carriageway.

The Author suggests that where Bullock-carts can be excluded it is possible to tar directly on kunkur surfaces. Our tour of inspection has however demonstrated that tar or Bitumen on kunkur does not stick well and the surface peels off soon. Will the Author please enlighten us whether his experience in Punjab is different to that in the United Provinces?

The idea of segregation of Bullock-cart traffic is an excellent one but looking to the funds available for road work it will be many years before we achieve this object.

While driving for miles and miles along a road which has big trees on either side, I have noticed that these trees cast shadows on the driving surface and the alternate light and shady patches make driving very tiring to the eye. So I may put it to the Congress for consideration whether it will not be more advisable to plant trees at such distance apart (across the road-way) that the shadows do not reach the driving track.

The author also refers to the advantages of shade to the life of tar or Bitumen. Bombay experience has proved otherwise. On account of rain dropping continuously at the same spot on the surface from these trees, it wears out the surface much quicker.

It may be interesting to note that Mr. Conner of United States Bureau of Public Roads recommends the following formula for road widening on curves :—

$$W = N\left(R - \sqrt{R^2 - L^2}\right) + \frac{V}{\sqrt{R}}$$

W = Total widening in feet.

N = No. of traffic Lanes.

R = Radius in feet.

L = Wheel-base in feet. (20 feet recommended).

V = Speed in miles, per hour.

The first part of the formula represents the extra width occupied by a vehicle on a curve and the second part allows for the difficulty of keeping a vehicle in the centre of the Lane. Widening is added in the inside of a curve.

It is stated in the paper that a traffic island is usually circular and with a radius of at least 80 feet.

My experience in Bombay in laying out traffic roundabouts is quite different from what is stated here. The islands are more of some other form than a circle as the shape of an island entirely depends upon the junction and the angles at which different roads meet. Besides with the majority of junctions in a city there is not enough room for a roundabout of 80 feet radius.

Mr. Trevor Jones (Author):—I am very much gratified that my paper has caused so much interest and I will endeavour to answer some of the questions put forth.

Mr. Bashiram has mentioned the unsuitability of brick kerbs to tarred surfaces. One of the difficulties of tarred surfaces, especially in the north of the Punjab, is that the edges are frequently broken away and may be a cause of accident when a vehicle passes from the metalled road to the berm. To some extent I feel that a kerb does prevent this, especially if you can back it up by some form of "pushta" of rough metalling.

As regards the stabilization of soil, it must be confessed that it is very much in its infancy.

I think Mr. Bowers suggested the addition of salt. In the Punjab we have got Dr. McKenzie Taylor, who is Director of the Irrigation Research and

a renowned soil physicist. He is at present analysing typical samples of soil from the Punjab as a preliminary to practical experiments. We are looking into the use of sodium carbonate and silicate of soda and common salt as is done in America, as it is hoped that such practice may be adopted for the stabilization of berms and Katcha roads.

Mr. Bashiram's remarks about the success of the provision of studs to segregate traffic on hill roads are of great interest. Nevertheless such studs have to be very carefully maintained and it is interesting to note that we have had a certain amount of complaints from the Automobile Association of Northern India as to their danger, possibly for the reason that these studs were placed at very narrow corners and did not provide sufficient carriageway.

As regards the remarks at the end of my paper that roads do not give an assessable return, what I meant to convey was that we can keep no profit and loss accounts of their construction and upkeep. I think there is no doubt about their benefit to the community, but we cannot express any benefit which may accrue to Government as in the case of Irrigation works, in so much hard cash.

Mr. Mitchell has rather accused me of inconsistency in that I stated that the Indian Road was a hastily begotten child and that later on I referred to the old days when there were roads sufficiently grandly planned to admit of at least three tracks. Of course I had not in mind the early days of road planning before the era of Railways when I made the first remark. There is no doubt that when the road was the only means of communication in the early days of British rule, a great deal of forethought for the future was practised and in the Grand Trunk Road and others we have a great and noble heritage.

Mr. Mitchell was not impressed with my objections to roadside fencing as he said that the land was excluded from the public for a very short time, only 2 or 3 years. The point that I would like to emphasise is that if you enclose these areas which are frequently in use by pedestrians, animals and bullock-carts off the main formation, you destroy the habit of their use and it takes a great deal of example or force to get them to use it again when the fence is removed.

I agree that the planting of trees should be 65 feet apart. It will be an excellent idea from the point of road safety. The 25 feet from the centre line is a compromise made to fit in with the existing scheme of things, the road formation being 32 feet from the road centre. This arrangement at least ensures that the tree is well down beyond the toe of the formation.

I think we are alive to Mr. Mitchell's criticisms about the road formation being banked like railway embankments. Most of our new road designs provide for slopes to be carried down from the edge of metalling to the side drain.

I was sure Mr. Sondhi would appreciate my remarks about berms. He was a great "scrounger" of spare metal lying alongside the Grand Trunk Road in the Jhelum District when he was my Sub-Divisional Officer some years ago and the excellent state of the berms today will testify to his activity.

The roundabout near the General Post Office at Lahore was admittedly an experiment and it is a very difficult place on which to site such a work. I am afraid however the tonga was not considered in designing the curves but the tarred road surface being slippery for horses it is just as well that the

tongawalas should exercise the care demanded of the motorist in negotiating the roundabout.

Mr. Dass Gupta's suggestions are undoubtedly very sound. The only really successful solution for berms is to abolish them by metalling but unfortunately that will cost money. You may improve berms but you must not spend money on them.

I am in full agreement with Mr. Nadirshah about super-elevation, a matter which has been much neglected in the past. The questions of curves, super-elevation, gradients, etc., are of the utmost importance in road projects, especially in the hill country and this has undoubtedly been neglected by us in recent years. What this shows is that for all road projects we must have proper surveys. In the past surveys for road projects have been done by the existing staff when they have sufficient time available. Consequently this aspect of the road project has not received the consideration it deserves and the best alignments, curves, etc., have not always been achieved.

I agree that 16 feet is not ideal but it is given in my paper as most of the roads in the N. W. F. P. are 16 feet and it is possible for two cars to pass each other slowly without using the berms

As regards tarring on kankar, I must admit I have had no great experience of it, but I have been told on good authority that the failures which occur are not through want of cohesion of the two materials but from the devastating action of the bullock-cart.

Chairman :—I join several others in congratulating Mr. Trevor Jones on his most valuable paper and the discussion which it has stimulated. However, as we have got only one hour left for the next paper which is a controversial one, I think we had better leave it at that.

CHAIRMAN :—Rai Bahadur Chhuttan Lal, (Retired Chief Engineer, United Provinces).

Chairman:—I call upon Mr. Dean to introduce his paper.

The following Paper was then taken as read.

Paper No. 34.

FURTHER NOTES ON TREATMENT OF ROADS WITH BITUMEN AND TAR IN DELHI PROVINCE.

[*Vide Proceedings of the Indian Roads Congress of December 1934, pages 21-51*].

BY

A. W. H. Dean, M.C., I.S.E., Superintending Engineer, Central Public Works Department, New Delhi.

I append a tabular statement giving details of all the road surface treatments mentioned in the original paper and have also included a few others.

The general experience of Delhi Province may be summarised as follows :—

1. *Tar*—Tar has definitely proved unsatisfactory, except the use of a high penetration tar as a first coat on water-bound macadam. The best use for this has been found to be painting it at the rate of 44 pounds per hundred square feet using 4 cubic feet of 3/8" Delhi Quartzite grit per hundred square feet. This has to be applied about three months after the surface of the water-bound road has been renewed, that is to say, when all the blinding has been worn off by traffic. Six months or more after the application of the tar, an application of a hot bitumen, *e.g.*, Spramex, or Socony, at the rate of about 25 pounds per hundred square feet with 4 cubic feet of 3/8" grit, has been found to give a very satisfactory surface for roads carrying mixed traffic up to 150 tons per yard width per day. 1" tar carpet, and 2½" tar carpet, water-bound tar Premix and mixtures of tar and bitumen, have all proved more or less unsatisfactory and are not recommended for further use.

2. *Emulsions.*—On the whole emulsions have not been found particularly successful either for painting, or for built-up carpets, *e.g.*, 1½" Armour coats, or for Premix 1" carpets. The most successful use of an emulsion for the initial treatment of a road has been Bitumuls Armour coat 1½". For use on a road which has some pot holes and where it is desired, to avoid the expense of renewing the whole surface by water-bound macadam before giving a bitumen treatment this is quite satisfactory. Another use for emulsions, and this in my opinion is the most useful field for their use, is for patch repairs. The facility with which emulsions can be carted about and used in small quantities without elaborate apparatus makes them particularly suitable for this work. Of the various types used Bitumuls and Colade have given the best results. This facility in use is also present in the case of certain cut-back bitumens *e.g.*, Socofix and Socofalt but our experience with these up-to-date is insufficient for a report. They have a higher bitumen content than emulsions and would appear to present several useful features.

3. *Carpets.*—PREMIX CARPETS. These have been laid 1", $1\frac{1}{2}$" and $2\frac{1}{2}$" thick. The only real success is with the $2\frac{1}{2}$". It is in my opinion definite that laying a carpet even of the maximum thickness is no cure whatever for a road with pot holes and other irregularities on the surface. Under traffic the carpet tends to reproduce in its surface all the depressions which were in the original surface. It is therefore, essential to lay such carpets on a road which is already, or is brought to, a smooth surface. I think that the 1" carpet with bitumen laid hot would be quite satisfactory if traffic could be confined to rubber tyred vehicles. This is not, however, possible, and the result of iron tyred traffic is cutting of the surface and deformation.

A $2\frac{1}{2}$" Shelcrete carpet was laid just over 3 years ago on the Hamilton Road. This carries particularly heavy traffic of all kinds and has stood up remarkably well. Another important point with regard to carpets is that these are essentially self-sealing under traffic and require a definite minimum intensity of traffic to give their best service. A carpet laid specially with a low penetration bitumen where traffic is not sufficiently heavy will show signs of cracking—indiscriminate use of such carpets is undoubtedly wasteful.

4. *Concrete Roads.*—These have been laid for such a short period that no indication of their life is possible. The surface is very satisfactory for mixed traffic, and particularly for heavily laden bullock carts. The bullocks appear to get a better grip than they do on a bitumen surface, and hence their tractive effort for a given load is less. The construction of a road to carry heavy mixed traffic with 8′ wide cement concrete strips on either side of a 16′ width surfaced with $2\frac{1}{2}$″ of Shelcrete or similar carpet would appear to be the best we have struck. If loaded cart traffic is almost all in one direction, one concrete strip would be sufficient.

Track Ways.—In concrete these proved entirely successful. Serious deformation has occurred in the bitumen carpet insets and this form of construction is not recommended. In the tar carpet insets this has been even worse. Some slight difficulty has been found with expansion joints. It is essential that these should be kept clear of all hard material.

It is very desirable to maintain the earth road between and on either side of the track ways specially in the hot weather; a small gang is necessary for this.

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Roads Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
Surface painting with Tar No. 2 with Chandigarh Ballast. *Materials* :— Tar No. 2. Chandigarh ballast.	4/34.	6/- % sft.	Mile 3 Furlong 4 of Delhi Rohtak Road.	Page 25	Soon after completion surface showed signs of breaking up; hence patch repairs were necessary. *Expenditure.* W. C. 50/- Materials. 100/- Total. Rs. 150/-	Heavy traffic specially village carts. 341 tons.	Surface was very bad. Deep patches have recently been repaired with W. B. Macadam & painted with Socony.	The road is not specifically mentioned.

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Roads Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
Surface painting with Tar Bitumen on Water Bound Road.	10/34.	5/4/0	Delhi Najafgarh Road M. 11 F. 1 to F. 8.	Page 36	No patch repair has been necessary. Minor attention has been paid to maintenance.	Light traffic specially lorries and tongas.	The coat has worn very thin.	One coat of hot bitumen over the surface will be necessary to keep it in good order.
Mixture A.					*Expenditure.*			
Tar No. 2. 75% Mexphalt 30/40 penetration. 25%			F. 5 to F. 8 of M. 11.		W. C. 400/- Materials. ... Total. Rs. 400/-			
Mixture B.								
Tar No. 2. 70% Mexphalt 30/40 penetration. 30%			F. 1 to F. 4 M. 11. Total. 8 furlongs.					

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Roads Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
Surface painting with Tar Bitumen on painted road.	11/34	2/8/-	Delhi Najafgarh Road Mile 6.	Pages 36-37	No patch repair has been necessary. Minor attention to maintenance has been paid.	Light traffic specially lorries and tongas.	Standing well.	
Mixture A.					*Expenditure.*			
Tar No. 2. 75% Mexphalt 30/40 penetration. 25%			F. 5 to F. 8.		W. C. for $1\frac{1}{4}$ years for 1 mile, 400/- Materials. ... Total. Rs. 400/-			
Mixture B.								
Tar No. 2. 70% Mexphalt 30/40 penetration. 30%			F. 1 to F. 4. F. 1 to F. 4. Total. 8 furlongs or 1 mile.					

Name and description of the treatment.	Date when done ; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Roads Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
Socony painting. *Materials:—* (*Standard.*)	3/32	4/14/0 % sft.	Furlong 6 of M. 2 of G. T. Road to Meerut.	ages* 21-22	*Expenditure.* W.C. for one year. 70/- Materials. 100/- Total. Rs. 170/-	Heavy traffic specially of 4 wheeled carts 571 tons.	Half the width of road was raised for giving super-elevation and then painted with Socony double coat in 3/34 while in the remaining width there were many deep patches which have recently been repaired with Premix of Socony and Bitumuls in 5/36.	*The road is not specifically mentioned.

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Roads Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
Surface painting with Bitumuls. Bitumuls HX 55% Bitumen content of 200 penetration. Stone chips spread over. $\frac{3}{4}''$ to $\frac{1}{8}''$ at the rate 3 cft. per % sft.	10/1934	6/8	F. 1 of M. 12 of Delhi Najafgarh Road.	*Pages 35-36	No patching has been necessary. Minor attention has been paid to maintenance *Expenditure.* W. C. ... 52/- Materials. ... Total. Rs. 52/-	Light traffic specially lorries and tongas.	Standing well	*Mile 2 F. 1 is wrongly stated as the situation of the experiment in the original paper.

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Roads Congress Proceedings Vol 1.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
Mix-in-place. *Materials.* *Binders.*	3/33	15/-		Pages 34-35.	Soon after the completion of the work, the surface showed signs of breaking up and ruts were formed. Extensive patch repairs were carried out soon afterwards.	Heavy traffic specially of village carts 341 tons.	Surface very bad & has recently been repaired with water bound patches and painted.	
(A) F. 70 and Mexphalt (30/40) penetration in proportion of 3 to 1.			F.5 to F.7 of Mile 3 of Rohtak Road.		*Expenditure.*			
(B) Colas Emulsion.			F. 6 and part of F. 8 of Mile 3.		W. C. Rs. 205/- Materials. Rs. 293/- Total. Rs. 498/-			

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, miles and furlong.	Reference to details in Road Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
Stanotread Treatment *Materials :—* Socony Asphalt grade 105 Socony Emulsion No. 3.	11/34	11/-	Muttra Road 1/2 of F. 2 F. 3, F. 4 & 1/2 of F. 5 of Mile 6 (3 furlongs).	Pages 47-48	About six months after the completion of the work the surface showed signs of breaking up. Patch repair was done with Colade, Bitumuls and Socony, *Expenditure.* W. C. 144/- Materials. 125/- Total. Rs. 269/-	All kinds of traffic specially of village & 4 wheeled carts and lorries. 1674 tons	Rough and broken up on sides.	

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Rate rence to details in Roads Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
Re-surfacing with 1" Tar *Carpet.* *Materials* :— Stone grit 1" to ¼" coated with Tar No. 2.	6/'34.	8/-% sft. & 3/8 % sft. for seal coat Total 11/8 % sft.	Parliament Street portion T to H/2 & Circus T.	Pages 26-27.	Expenditure on maintenance is negligible so far.	Mixed class traffic especially Motors and heavy carts.	Surface standing well but has become bumpy at edges due to accumulation of material at places due to creep under traffic.	Does not appear to be as good as Shell-sheet.
-do.-		-do.-	Queensway B to E & E to S/2.	-do.-	Extensive patch repairs done, at a cost of Rs. 1,000 approx.	Mixed class -do.-	Surface bumpy at shoulders & needs continuous patch repairs after removing the bumps.	-do.-
-do.-		-do.-	Raisina Road X point to Great Place.	-do.-	Expenditure on maintenance is negligible so far.	Mixed class traffic, specially fast traffic of Motors and lorries.	Surface rough & dry. May need a seal coat early.	-do.-
1" Tar Carpet. *Materials:* — Tar No. 1 at 240° F. Tar No. 2 at 250° F. & Tar No. 3 at 260° F. Metal ¾" to ½" 60% ⅜" to ⅛" 40%	10/34.	10% sft.	Great Place.	Page 27	-do.-	-do.-	-do.-	-do.-

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Roads Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
1" Carpet Ormul Emulsion. *Materials.* Ormul emulsion. Stone grit passing 1" & retained on $\frac{1}{2}$" mesh.	3/34	10/-	M. 5 F. 6 to F. 8 of Muttra Road.	Page 34	Soon after the completion the surface showed signs of breaking up. Patch repairs with Colade, Socony and Bitumuls have been done. *Expenditure.* W. C. for 2 years of 3 furlongs. 216/- Materials. 184/- Total. Rs. 400/-	All kinds of traffic specially of village and 4 wheeled carts and lorries. 1674 tons.	This has definitely failed to stand upto traffic satisfactorily. Surface is wavy due to accumulation of bitumen in places.	$2\frac{1}{2}$" thick Shelcrete will have to be put in to replace this.

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Road-Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition	Remarks.
1" Carpet with Colfix. *Materials* :— Colfix 55 to 60% bitumen content. (Spramex of 200 penetration).		9/- % sft.	Queensway point X to B and Circus X	Page 33	Expenditure on maintenance is negligible so far.	Mixed class traffic specially heavy carts, Motors and lorries.	Surface bumpy at shoulders due to accumulation of material at places. Now needs patching to make the surface smooth after cutting the bumps.	Does not appear to be as good as Shell-sheet.
Re-surfacing with 1" *Hot Socony Premix.* *Material.* Socony Asphalt Grade 101.	6/34	9/8/- % sft.	Parliament Street from point H/2 to O/4, including Circus H/2.	- do.-	Nil.	Mixed class traffic specially heavy carts, Motors and lorries.	Surface standing well. No cracks have appeared.	Practically as good as 1" Shell-sheet.

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Roads Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
Re-surfacing with 1" *Shell-sheet.* *Materials* :— Mexphalt 10/20 penetration and Shellmac in the proportion of 2 of the former to 1 of the latter.	9/32	9/- % sft.	Queensway D to X. (a) Portion U/5 to Keeling Road junction.	Page 26.	Expenditure on maintenance is negligible so far.	Mixed class traffic especially motors and heavy carts.	Surface is intact and has not required any patching so far although the stones show sign of wearing. The carpet has however cracked extensively in the middle third of the 40 ft. width.	1" Carpet appears to be too thin to stand traffic. Mexphalt of 10/20 penetration is not good for such work.
Mexphalt 20/30 penetration & Shellmac in the proportion of 2 of the former to 1 of the latter.	6/34.	9/- % sft.	(b) Queensway portion Keeling Road to Petrol filling station.	- do.-	-do. -	-do.-	-do.- but no cracks have appeared so far.	
-do. -		9/- % sft.	Parliament Street D to Jantar Mantar.	- do.-	- do.-	- do.-	- do.- no cracks so far.	

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Roads Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
$1\frac{1}{2}''$ Armour coat with Tar Bitumen Mixture. *Materials* :— *Mixture A.* Tar 75%. Bitumen. 25%. *Mixture B.* Tar 70%. Bitumen. 30%.	10/34	15/8	G. T. Road to Karnal 2/4 to 2/7. F. 6 & 7. F. 4 & 5.	Pages 30-32.	Some patching in F. 2-7 and 2-6 has been necessary. A little attention has been paid in maintenance to the rest. *Expenditure.* W. C. for 1-5/12 years for 4 furlongs. 260/- Materials. 25/- Total. Rs. 285/-	All kinds of traffic specially village carts and tongas. 832 tons.	The surface is uneven.	Not very good.

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Roads Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
$1\frac{1}{2}$" Armour coat with Colas Emulsion.	9/34	12/-	In 2/8 & 3/1 of G. T. Karnal Road.	Page 30	Some patching has been found necessary. *Expenditure.* W.C. for $1\frac{1}{2}$ years for 2 furlongs. 130/- Materials. 93/- Total. Rs. 223/-	All kinds of traffic specially village carts and tongas. 832 tons.	Standing fairly well.	Armour coat with bitumuls has stood better than Colas.

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Roads Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
$1\frac{1}{2}''$ Armour coat with Bitumuls. *Materials :—* Bitumul Emulsions Aggregates :— Stone metal 1" to $\frac{3}{4}''$.	10/34	14/-	In F. 3/2 and 3/3 of G. T. Road to Karnal	Pages 28-29	No patching has been necessary with this treatment. Minor attention has been paid to maintenance. *Expenditure.* W. C. for 1 5/12 years for 2 furlongs. 130/- Materials. ... Total. Rs. 130/-	All kinds of traffic specially village carts and tongas. 832 tons.	Standing very well. Slight depressions.	

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Roads Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
Grouting with Mexphalt and Seal coat of Spramex. *Materials.* Metals $1\frac{1}{2}''$ to $\frac{3}{4}''$. Mexphalt 30/40 penetration. Stone grit. 3/4" to 1/8".	1926 & 1927	2/- sft.	From Paharganj junction to Nabi Karim junction Qutab Road M. 1.	Pages 21 & 50	Patch repair has been done whenever necessary. *Expenditure.* W. C. 400/- Materials. 420/- Total. Rs. 820/- for one year only.	All kinds of traffic (city portion).	Has stood well but now it is showing signs of breaking up and patching is being done.	
$2\frac{1}{2}''$ Grouting with Asphalt Mexphalt. *Materials*:— Stone metal $1\frac{1}{2}''$ to $\frac{3}{4}''$ Mexphalt 30/40 Penetration. Stone grit $\frac{3}{4}''$ to $\frac{1}{4}''$.	3/1933	2/- sft.	F. 1st. of M. 2 and F. 8 to F. 2 of M. 3 of G. T. Road to Meerut.	Page 22	No patching has been necessary. Minor attention has been paid for maintenance. *Expenditure.* W. C. 1120/- Materials. ... Total. Rs. 1120/-	Heavy traffic specially of 4 wheeled carts. 571 tons.	Standing well.	

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Roads Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
$2\frac{1}{2}''$ Grouting with Hot *Socony.* *Materials* :— Stone metal $1\frac{1}{2}''$ to $\frac{3}{4}''$. Asphaltum 101. Stone grit $\frac{3}{4}''$ to $\frac{1}{8}''$.	3/1933	2/6/- per sft.	F. 1 of M. 3 & F. 8 to F. 6 of M. 4 G. T. Road to Meerut.	Pages 22-23	No patching has been necessary. Minor attention has been paid for maintenance. *Expenditure.* W. C. 840/- Materials. ... Total. Rs. 840/-	Heavy traffic especially of 4 wheeled carts. 571 tons.	Standing well.	
$2\frac{1}{2}''$ Water Bound Tar Macadam. *Materials* :— Shalimar Tar No. 2.	4/34	6/8/-	1-2 F. 4 1-2 F. 5 Rohtak Road Mile 3.	Pages 45-46	Soon after the completion the surface showed the signs of breaking up hence patching was necessary. *Expenditure.* W. C. for 2 years for 2 furlongs. 200/- Materials. 50/- Total. Rs. 250/-	Heavy traffic specially village carts 341 tons.	Surface bad. There are many deep patches which have recently been repaired with Water Bound Macadam and painted with Socony and Bitumuls.	Not good.

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Roads Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
2½" Premix Macadam finished coat. *Materials:—* Standard.	6/33	2/- per sft.	Hamilton Road.	Pages 23-25	No patching has been necessary with this treatment. Minor attention has been paid for maintenance. *Expenditure.* W. C. Rs. 875/- Materials. ... Total. Rs. 875/-	All kinds of traffic especially 4 wheeled carts.	Standing well.	
2½" Trinimac. *Material:—* Trinimac Asphalt and Flux oil 80 parts of the former and 20 of latter.	11/34	22/4/-	G. T. Road to Meerut F. 3 of Mile 3.	Page 47	No patch repair was done. Minor attention has been paid to maintenance. *Expenditure.* W. C. 93/- Materials. ... Total. Rs. 93/-	Heavy traffic specially of 4 wheeled carts. 571 tons.	Standing well.	

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Roads Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
$2\frac{1}{2}''$ Tar Carpet with Seal coat applied at once. *Materials:*— Shalimar Tar No. 2.	11/34	21/-	Portion of F. 7 & $\frac{1}{2}$ of F. 8 of Mile 2 Rohtak Road.	Pages 25-26	Some patching has been necessary. Minor attention has been paid in maintenance. *Expenditure.* W. C. for $1\frac{1}{3}$ years for 1 furlong 62/- Materials. 13/- Total. Rs. 75/-	Heavy traffic specially village carts. 341 tons.	Surface very uneven.	
$2\frac{1}{2}''$ Tar Carpet with Seal coat applied after 2 months. *Materials:*— Shalimar Tar No. 2.	4/34	18/8/- 2/8/- respectively.	F. 3 & 4 of M. 4 of Rohtak Road.	Pages 25-26	Surface showed signs of breaking up and patch repairs were necessary. *Expenditure.* W. C. for 2 years 200/- Materials. 40/- Total. Rs. 240/-	Heavy traffic specially village carts. 341 tons.	The surface is very uneven and bad.	

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Roads Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
$2\frac{1}{2}''$ Tar Carpet with seal coat. *Materials:—* Standard.	4/34	21/-	F. 8 of M. 2 along 8′ cement concerte Rohtak Road.	Page 44	No patching has been necessary. Minor attention has been paid to maintenance. *Expenditure.* W. C. 25/-. Materials. ... Total. Rs. 25/-	Heavy traffic specially village carts. 341 tons.	Surface uneven.	

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Roads Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
$2\frac{1}{2}$" Shelcrete. *Materials.* Standard.		21/-	Qutab Rd. from Connaught Place to its junction with Paharganj about $\frac{1}{2}$ mile.	*Pages 24-25	No expenditure has been incurred in the maintenance of Shelcrete.	Heavy traffic specially village carts. 380 tons.	Standing well.	*The road is not specifically mentioned.
- do. -	12/34	21/-	Portion of F. 1 of M. 8. along 8′ cement concrete Rohtak Road.	Page 44.	- do. -	- do. - 152 Tons.	- do. -	

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Roads Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
$2\frac{1}{2}''$ Shelcrete. *Materials* :— Standard.	4/34	21/-	F. 8. of M. 3 F. 1 & portion of F. 2 of M. 4 Rohtak Road.	*Pages 24-25	No patch repair was done. Minor attention has been paid to maintenance. *Expenditure.* W. C. Rs. 250/- Materials. ... Total. Rs. 250/-	Heavy traffic specially of village carts. 341 tons.	Standing well.	*The name of the road is not specifically mentioned.
$2\frac{1}{2}''$ Shelcrete. *Materials* :— Standard.	5/35	1 /-	F. 1 to F. 5 of M. 3 of Delhi Muttra Road.	*Pages 24-25	No patch repair was done. Minor attention has been paid to maintenance. *Expenditure.* W. C. for 1 year. 180/- Materials ... Total. Rs. 180/-	Heavy traffic specially of village carts 1672 tons.	Standing well.	*The road is not specifically mentioned.

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Roads Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
$2\frac{1}{2}$" Shelcrete. (Standard).	1935 and 11/34	21/- % sft.	F. 7 & 6 of M. 2 & F. 5 & 4 of M. 4 of G.T Road to Meerut.	Pages 24-25	No patching has been necessary. Minor attention has been paid for maintenance. *Expenditure.* W. C. 610/- Materials. ... Total. Rs. 610/-	Heavy traffic specially of 4 wheeled carts. 571 tons.	Standing well.	
$2\frac{1}{2}$"Hot Socony Premix. *Materials :—* Bitumen Hot Socony Asphalt grade 101 of Standard Vacuum Oil Co. Aggregate. For Binder coat $1\frac{1}{2}$" to 1" stone metal. For wearing coat $\frac{3}{4}$" to $1\frac{1}{2}$" stone grit.	11/34	17/8/-	F. 2 and F. 3 of Mile 1 Meerut Road.	Page 46	No patch repair has been done. Minor attention has been paid to maintenance. *Expenditure.* W. C. Rs. 197/- Materials. ... Total. Rs. 197/-	Heavy traffic specially of 4 wheeled carts. 571 tons.	Standing well but surface is slightly wavy.	

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Roads Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
Cement Concrete 6"-4"-6". *Materials.* *Cement* :- Bundi Portland cement. *Badarpur Sand*:- Mostly of Budhiya Nala. *Aggregate* :—Jhandewala quarries 60% $1\frac{1}{2}''$ to $\frac{3}{4}''$. 40% $\frac{3}{4}''$ to $\frac{1}{8}''$.	10/34	34/-	Rohtak Road $\frac{1}{2}$ of F. 8 of M. 3 $\frac{1}{2}$ of F. 1 of M. 3.	Page 44	No maintenance expenditure has been incurred in cement concrete.	Heavy traffic specially village carts. 341 tons.	Surface very good.	This is the best under very heavy traffic.
Cement Concrete 7"-5"-7" *Materials.* *Cement*:- Bundi Portland cement. *Badarpur Sand*:-Mostly of Budhiya Nala. *Aggregate*:—Jhandewala quarries 60% $1\frac{1}{2}''$ to $\frac{3}{4}''$ 40% $\frac{3}{4}''$ to $\frac{1}{8}''$.	6/34	58/-	$\frac{1}{2}$ of F. 1 of M. 3 F. 2 & $\frac{1}{2}$ of F. 3 of Mile 3 Rohtak Road.	Pages 37-44	No patching but filling into joints has been done from time to time. Minor attention has been paid to maintenance. *Expenditure.* W. C. 180/- Materials. 20/- Total. Rs. 200/-	Heavy traffic specially village carts 341 tons.	Surface very good.	This is the best under very heavy traffic.

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Roads Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
Cement Concrete 7"-5"-7". *Materials.* Same as in previous.	11/34	58/-	F. 4 & 5 of Mile 1 of Meerut Road.	Pages 37-44	No patching is done only filling into joints has been necessary. *Expenditure.* W. C. 197/- Materials. 20/- Total. Rs. 217/-	Heavy traffic specially of 4 wheeled carts 571 tons.	Surface very good. A few abrasions have appeared.	

Name and description of the treatment.	Date when done; month & year.	Cost per cent. sft.	Site, road, mile and furlong.	Reference to details in Roads Congress Proceedings Vol I.	Brief note of any maintenance expenditure to March 1936 & what maintenance has been done.	Note on the nature of traffic and total load on road for 24 hours.	Note on the present condition.	Remarks.
Trackways on Badli Approach Road.								
1. Bharatpur stone slabs 4" thick.			200 ft.	Pages 48/50.	No patch repair. Minor attention in maintenance has been paid. *Expenditure.* W. C. 150/- Materials. 25/- Total. Rs. 175/-	Mostly bullock cart traffic.	They are all standing well within their limitation.	
2. Plain cement concrete tracks 6" thick.			1½ ft.					
3. Cement concrete tracks with reinforcement of Mild steel bars at top and bottom.			½ furlong					
4. Plain cement concrete tracks 6" thick inlaid on top with 1" Shelsheet.			1 furlong.					
5. Cement concrete tracks with M.S. reinforcement at top and bottom inlaid with 1" Shelsheet.			1 -do.-					
6. Cement concrete tracks 3" thick over 6" lime concrete.			1 -do.-					
7. Cement concrete tracks 3" thick over 6" lime concrete inlaid with 1" Shelsheet.			1 -do.-					
Aggregates consisted of the following grades of stone ballast.								
1. Passing $1\frac{1}{2}''$ and retained on $\frac{3}{4}''$ 60%.								
„ $\frac{3}{4}''$ „ $\frac{1}{8}''$ 40%.								
2. „ $\frac{3}{4}''$ „ $\frac{3}{8}''$ 60%.								
„ $\frac{3}{8}''$ „ $\frac{1}{8}''$ 40%.								

DISCUSSIONS ON PAPER No. 34.

Mr. A. W. H. Dean (Author) :—I have no introductory remarks to make, but I want to say that this paper was written at the instance of Mr. Mitchell who said that having written the earlier paper in 1934 I ought to give some notes as to how the various surfaces which were then described and shown to you who were at the first Roads Congress at Delhi had stood up in the intervening two years and three months, I have merely tried to tabulate my own impression of how these roads now are. I am unfortunately not in charge of roads at the moment, so I have not been able, in consequence, to get quite so much information about them and refer to details in quite the way I would otherwise have been able to. I am afraid there may be some mistakes in correlating the figures I gave last time and the figures I have given this time on that account. I may also say that I have perhaps been a little sweeping in some of the things I have said. I did not appreciate that, but I thought it was quite understood that my remarks referred to the actual roads in Delhi under Delhi conditions.

Mr. S. Bashiram (Punjab):—Mr. Chairman and gentlemen, I take it that what Mr. Dean means by "high penetration tar" in para 1 of his paper is tar No. 1. I have not seen mentioned anywhere in this paper or in the previous paper referred to whether tar No. 2 was actually used in Delhi or not. In Delhi the first coat of tar is given, so Mr. Dean says, three months after the surface has been renewed. In the Punjab it is our practice to put on tar as soon as the consolidation has dried; this takes about 15 days to a month. We also find that it is extremely easy to brush off the blinding. Our blinding consists generally of earth and not of moorum and we find that to make tar painting a success, it is absolutely essential that the surface below, *viz.*, the water-bound macadam, must be well consolidated and the top sufficiently cleaned to allow of penetration. My beat in my own area takes me sometimes across the border into Delhi Province and certainly our ideas in the Punjab about consolidation are somewhat different, if I may respectfully say so, from those that seem to prevail there. From the Punjab point of view the consolidation there is not quite so good as it can be or should be. There is too much mud or moorum used and you really get a sort of plum pudding. May I suggest that this failure of tar in Delhi is possibly due to unsatisfactory consolidation and insufficient penetration ?

At no place in this paper has mention been made of the temperature to which the tar was heated, and that is a very vital point indeed, as overheated tar fails quickly and I suggest that you cannot be too careful about this overheating. In my own circle there are instructions that the temperature should not exceed (on paper only) 200° F. During one of my tours, although the Road Inspector said he knew of this order, when I took the temperature myself I found that it was actually 245°. Now there are various difficulties in taking this temperature. One of them, as you know, is the fumes that come up and prevent you from taking your eyes very close to the utensil in which tar is heated. Also there are not, at least I have not come across them, any satisfactory thermometers. I was suggesting this morning to my friend, Colonel Sopwith, that in the interests of his material he should try to get out a thermometer with a broad mercury thread such as we see in the small clinical thermometer which starts at 95°. I suggest that our thermometer should start at 150° and go up to 300 degrees or so. There should also be on it a suitably coloured line, say, at 200° so that the coolie or the mate in charge would know at once when the danger point is reached and lower the fire immediately.

I may mention that the quantities mentioned in Mr. Dean's paper vary very much from our normal practice in the Punjab, and it may not be out of place to mention what our standard practice is. Most likely most of the members already know what it is. Our standards are based on a 12 feet wide mile and we use for the first coat 8 tons of tar per mile and bajri at 250 cubic feet per ton. For our second and subsequent coats we use only 4 tons of tar and the quantity of bajri is 300 cubic feet per ton. Mr. Dean has used 13½ tons of tar per 12 foot wide mile and the quantity of bajri is 190 cubic feet per ton. Reading through the paper it appeared to me—and I am subject to correction—that in Delhi they have not done any two coat work with tar.

To make tar painting a success your bajri must be really good. The bajri that they use in Delhi is exactly the same as we get round about Gurgaon and we have therefore experience of it. While that bajri is sufficiently good for the first coat, it certainly is not so good for the second or subsequent coats. It is angular and that of course is a good thing to have, but unfortunately it is brittle as well and there of course the mischief comes in. It powders into dust very quickly. The reason why it is good for the first coat is that it affords a very good grip for the top bajri. Provided the top bajri used is satisfactory, such as Chandigarh, tarring is successful. This possibly is another reason of failure of tar in Delhi.

On page 29 of this paper Mr. Dean has mentioned a rate of Rs. 6/- per cent square feet of the surface treated and the entire traffic as 341 tons. Actually on the quantities that I have given, our rates in the Punjab are Rs. 2/8 per cent square feet for the first coat and Rs. 1/8 for the second and subsequent coats and you will be surprised what traffic our roads are able to take. In my own circle there are at least 200 miles where the traffic is much greater than the 150 tons per yard width mentioned by Mr. Dean. As a matter of fact there are places in the Punjab where our normal specifications are standing up quite well against 350 tons per yard width of road. In the Punjab we have very little experience with tar carpets, and some experiments are being made now, but I can say that surface painting with tar has done us remarkably well. Bitumen is an excellent material but it will not do to condemn tar which is a cheaper material, more fool-proof and very much less seasonal in its applicability.

Mr. R. L. Sondhi (Punjab):—Chairman and Gentlemen. Most of what I had to say, my Superintending Engineer has already said, but still I must make an attempt. Road experiments under actual traffic conditions and kept under observation for a number of years are sure to give very useful and valuable information as regards comparative utility of different specifications and Mr. Dean's paper is a very valuable contribution and I congratulate him for the excellent way in which he has presented the information.

There are, however, a few points on which I would like him to throw further light. Realising the difficulty in comparing specifications and carts this Congress at its last session at Bangalore had recommended the adoption of certain standard units of weight, measure and cost (vide page 176 of the Proceedings of the Second Indian Roads Congress). It is, however, noticed that the author has not followed the recommendations. The reasons put forward by the Congress in making these recommendations, will be generally accepted and it will be interesting to know as to why the author has not adopted this suggestion in describing the experiments and their results in the present paper.

I am afraid the remark that tar has definitely proved unsatisfactory is too sweeping, and before condemning this material which has proved useful on

roads radiating out of the Delhi Province and just beyond its limits, I think a further trial is needed under careful supervision and examination of constituent materials, particularly aggregate and grit is required. The traffic conditions on the trunk roads, radiating out of Delhi cannot be expected to vary much on the portions in the Punjab bordering on Delhi and it is there that the tar painting done by the Punjab engineers has definitely stood up to the traffic.

In view of the fear raised in the †Paper of Messrs. Sinha and Abbasi last year about the wear of this class of surface as a result of the graphs prepared by profileograph, it is gratifying to learn from Mr. Dean's remarks on concrete roads that this surface is very satisfactory for mixed traffic and particularly for heavily laden bullock-carts. I think the delegates will remember that it was shown in that Paper that 1¼ inch of crust had got worn in the course of a year or so, but it is pleasing to know from the Superintending Engineer of that road that these concrete roads are standing the mixed traffic very well. Therefore, there must have been some mistake in preparing those graphs.

The author has used the term "light traffic" in the tabular statements appended to the paper but has not defined its extent. It will perhaps be instructive if he will kindly define what intensity of traffic he considers light. It is not clear from what is stated at page 29 of the Paper as to whether the cost of Rs. 6/- per 100 square feet is for one or more tar paintings, as Mr. Bashiram has pointed out that our tar painting did not even cost Rs. 3/- per hundred square feet. If a single coat was applied it is no wonder that it failed under the specified traffic, as a second and subsequent coats should have been applied in due time. The second coat should, if possible, be applied immediately after the first. That is our practice in the Punjab. We do not allow our first coat to stand for a long time and if we apply the second coat soon after, it stands much better. The interval of three months recommended by the author to be allowed to lapse before painting the water bound surface with tar is, in my opinion, too long and possibly was one of the causes of failure of the surface. As stated by Mr. Bashiram, only 15 days to a month should be ample.

The total traffic given by the author in mile 3 furlong 4 of Delhi Rohtak Road is 341 tons. This figure appears in all the experiments relating to this mile; whether they are concrete or tarred surfaces. This figure differs a great deal from the figure of 772.9 tons which represents the total traffic at that place according to the statement at page 19 of the proceedings of the Second Indian Roads Congress. Similarly, there is a great variation in the traffic figures as given in the author's Paper and my Paper‡ about Delhi Traffic Census. On Grand Trunk Karnal road the author's figure is 823 tons whereas according to Delhi Traffic Census it is 567 tons; on Grand Trunk Meerut road the figure given by the author is 571 tons against 1282 tons determined by me and on the Delhi Muttra road the figures are 1674 tons and 1295 tons respectively. I hope the author will kindly explain these variations.

Colonel G. E. Sopwith:—Mr Chairman, I wrote this before the Congress meeting and one or two points mentioned by me have already been dealt with in other speeches. Mr. Dean states that in Delhi painting a first coat of tar at 0.36 gallon per square yard (44 pounds per 100 square feet) followed by a second coat of Bitumen at 0.23 gallon per square yard (25 pounds per 100 square feet) has given satisfactory results up to 150 tons per yard width per day. This apparently means only 50 tons of bullock cart traffic judging from the author's

†Proceedings of the Second Indian Roads Congress, Paper No. 15.

‡Proceedings of the Second Indian Roads Congress, Paper No. 14.

reply in the discussion on his Paper No. 1-A read in 1934 (Proceedings of the Inaugural Indian Raods Congress, 1934). As tar painted roads elsewhere are successfully standing up to traffic of much greater intensity than this (for instance the traffic on the Lahore Lyallpur road varies from 278 to 352 tons) the cause of the less fortunate experience in Delhi is worth careful investigation and analysis. I do not doubt that investigation has been made but I suggest that the paper, which tends to lay the blame for partially unsatisfactory results on the various binders, would have had it's value enhanced by embodying in it the results. Similarly thin and thick carpets are noted as more or less unsatisfactory and the author makes a recommendation against their further use. I presume that this recommendation is only intended to apply to the restricted locality of Delhi since experience with these methods of treatment has been more fortunate elsewhere.

To quote Mr. Brown's remarks during the discussion on Papers 2,5(a), 5 (b) and 6 read at the Inaugural Indian Roads Congress in 1934.

"We are perhaps inclined to forget that it is the stone which carries the traffic and that when we discuss the failure of surface dressings, we are apt to blame the dressing when very often we should blame the stone base."

Most of us I think are aware that some at least of the Delhi stones though hard are brittle and have a definite tendency to crush under roller or traffic, although in some parts of the Punjab, Delhi stone painted with tar is used with better results than apparently Delhi has experienced. It does, however, lead to a considerable quantity of moorum or earth binder being used during consolidation and we would welcome a statement from the author giving the quantity of earth binder and also the rate of consolidation per day laid down in the Delhi specifications, since thorough consolidation and interlocking of metal are of much importance in obtaining the best results.

I have personally investigated portions of thick tar carpets that have formed into potholes and found that in some instances the stone underneath had crushed into powder and in others that the ground was waterlogged and sinking had occurred. As soon as a crack ever appears dust enters, the tar absorbs it and break-up starts. Faced as we are by imperfect grading since only hand broken metal is available, the machinery for breaking to exact grading being usually too expensive except for very extensive work, there is no question that the voids between pieces of stone metal are not always completely filled and full lateral and vertical support is consequently absent. I dealt with this point in Paper No. 20 read at the Second Indian Roads Congress, Bangalore, 1936. It seems, therefore, that for Delhi conditions some other form of construction is desirable, when making Premix carpets and extensive experiment and research into using sand with the metal to overcome this difficulty has resulted in the production of greatly improved carpets. But perhaps the best of all, where conditions of traffic necessitate something more elaborate than tar painting, is Tar Pitch Grout which will carry extremely heavy traffic and shows no tendency to wave.

I have dealt above with the difficulty that brittle stone produces but where hard tough stone is found and crushing does not take place Premix carpets show none of the defects which have been found in Delhi and carpets made of tough stone have been completely successful in many other parts of India.

For economic reasons I personally am an advocate of tar painting and if Delhi stone by reason of its brittleness does not lend itself to the formation of a road really suited to painting, I suggest consideration of substituting broken well

burnt brick for the stone. This can be economically burnt specially in clamp kilns and would do away as experience has shown with the difficulty now experienced of having to use an excessive quantity of earth binder which lessens the penetration of the first coat of tar and I cannot too strongly emphasize the importance of penetration in creating a fully stabilised road. In passing I should like once more to say that the sooner tar is applied after consolidation the better the result. It should be applied as soon as the road has dried out which may be from 4 to 21 days and only in exceptional circumstances should it be more than one month. The author writes of three months as the period between consolidation and tarring by which time the blinding has been worn off by traffic, but I respectfully beg to differ from this dictum and to say that if possible no blinding should be used or, if it is essential by reason of the quality of the stone, the minimum amount and that only of loam should be utilised. The quicker the tar is applied the less time is there for deterioration of the metal, which traffic sets in motion, to proceed.

For Premix carpets too, broken brick is eminently suitable but naturally the greatest care must be taken that no under-burnt material is incorporated.

The author has kindly informed me that the only two roads on which tar has been applied as a second coat instead of bitumen are Albuquerque Road and the Ridge Road. The former is not an important road and when painted had a gravel surface of some age. It was not really suitable for painting but since the traffic was small and mostly motor it seemed worth risking it. The Ridge road's second coat I inspected a few days ago. I cannot claim it as an advertisement. In many places it shows a bad appearance and undoubtedly tar has been burnt by the contractor while there are definite indications that internal movement of the stone has taken place due to insufficient penetration by the first coat. Extensive experience elsewhere has shown that tar painted roads, given good interlocking metal and correct application of binder give a very definite saving in maintenance cost which can be applied towards the improvement of further lengths of road and I submit that only by this application of savings to decreasing the length of untreated roads can large scale rapid improvement be attained. It is the untreated roads that eat up money if they are to be kept in good condition, and as sufficient money is not available a deplorable condition arises which entails great loss to the road user.

Mr. K. G. Mitchell (Government of India):—I would like to say on behalf of the Congress management that I am very much obliged to Mr. Dean for having taken the trouble to compile his paper. I think it is important that there should be a continuity in the papers which are presented to the Congress otherwise we are apt to forget and be unable to recall after two or three years the things we discussed before. I do not propose to enter into the somewhat controversial subject of why tar has not been so successful in Delhi as it has been elsewhere, under comparable traffic between the Delhi and neighbouring roads. But I think probably, as Col. Sopwith has said, it is due to something in the stone. It might be of interest to the Congress to know that the Technical Sub-Committee, which is considering the scheme of tests to be made on the Test Track at Calcutta has recommended that the first thing to do is to work out a correlation between the behaviour of aggregates and chippings in surface painting work with the results obtained by tests in the Deval Machine, so as to see whether the results in practice are the same as given by the machine. I cannot miss the opportunity of riding my particular hobby horse and I would like to draw attention to the last paragraph but one of the Paper in which the writer has referred to Track Ways. He says "In concrete these proved entirely successful". He reports serious defects in the bitumen and tar carpet insets

The more I consider the problem of improving unmetalled roads to carry the ever-increasing bullock-cart traffic the more certain I feel that little or nothing that can be done to the soil will enable it to bear the weight of heavy bullock-carts. There is not enough money in the world to metal the roads which are at present unmetalled and which are cut into deep ruts by these carts. I have recently had a look at the track-ways in the Punjab and also those which Mr. Dean has mentioned. I am certain that something on these lines is the only solution. We are going to investigate and have made arrangement for research into the qualities of soil. But this will only carry us to a certain distance. I do not think any financial arrangement you can conceive of is going to enable you to maintain double the existing milage of metalled roads. If these track-ways are successful our unmetalled roads can for all ordinary intents and purposes, be kept up at a cost of Rs. 100 to 200 per mile a year and can be kept in fairly good condition, satisfactory for the purpose. That seems to be one possible solution, and I would quite definitely recommend it to every body and every province to try and see how it works.

Mr. G. B. Vaswani (Sind):—Mr. President and Gentlemen—I want to give you some more information about the use of emulsions.

In Karachi, the streets in Old Town Quarter were originally provided with stone pavement set in lime mortar cement pointed on foundation of dry broken metal 6 inches in depth. So long as the streets were narrow, there was only pedestrian traffic on them along with light traffic of hand carts. As soon as the Municipality acquired land and widened the streets, they have been subjected to heavy motor lorry traffic loaded with stone, broken metal and gravel for the construction of buildings. This has resulted in breaking up the cement concrete at the joints, as a result of the movement produced in the stones due to unevenness of the bed. The stones were pointed once again with cement mortar but within a short time, the pointing gave way and therefore a substitute had to be found out to replace the cement pointing.

The mixture of Socony Emulsion No. 3 with sand in the proportion of about 7 pounds of Emulsion per one cubic foot of sand was made and filled in the joints after raking and giving a coat of Emulsion. This method proved successful and gave satisfactory results and it is now being used wholesale for repairs of stone pavement.

In cases of depression and unevenness in the stone pavement, the stones are given a dab coat with Emulsion and the above mixture of Emulsion and sand is spread over it to make up for the unevenness and this has also been found very successful and it has resulted in saving cost of stone repairs by 70 per cent.

The cost of cement pointing is Rs. 4/- per 100 square feet whereas the cost of Emulsion pointing is about one rupee per 100 square feet.

2. In the Elphinstone Street of Karachi the footpaths were provided with stone pavement and on account of age and traffic had become most uneven. It was proposed to renew the footpaths with cement concrete which would have cost the Corporation about Rs. 15/- per 100 square feet plus the charges for the removal of the stone pavement. Here again the mixture of sand and emulsion was applied in about ½ inch to ¾ inch thickness to cover up the unevenness after painting the stones with a coat of emulsion. The footpath was rolled with hand roller and closed to traffic for 24 hours. This entirely

changed the appearance of the footpath from stone pavement to asphalt and it has been standing well for the last two years.

3. In this Corporation, it was a problem how to make cheap roads to stand heavy traffic. In Karachi we have got camel-carts which carry about 32 maunds of load and bullock-carts with iron tyres and they tear away surface painted roads within six months time.

I made an experiment with premix using gravel and sand mixed with Socony Emulsion and laying it in 1 inch thickness over the road. This did not prove so successful at first, because the thickness was not sufficient, and it went into corrugation on account of roundness of the gravel. Therefore, another experiment was made with premix $1\frac{1}{2}$ inches thick in which one part of chippings, two parts of gravel, two parts of sand and 2.7 gallons of Socony Emulsion were used. In this case, the surface was first given a coat of Emulsion and then the above mixture was placed to a thickness of $1\frac{3}{4}$ inches and consolidated with a hand roller to $1\frac{1}{2}$ inches. The road was closed to traffic for about five days and then a heavy roller was passed over the surface and then the road was open to traffic. This has proved very successful on Lakhmidas Street, Grant Road, Bunder Road etc. The cost of this mixture works out to annas 8 to 10 per square yard and I consider it to be the cheapest method of construction for moderately heavy traffic.

We have in Karachi 140 miles of roads and the Budget provision for asphalting new roads and the maintenance of the existing roads is about Rs. 80,000/-. Most of the roads are surface painted and I find that by adopting cheap methods we have been able to maintain roads in proper condition.

Mr. Dean (Author):—Mr. Chairman and Gentlemen, first of all I feel after what Mr. Bashiram and Mr. Sondhi have had to say that I must disclaim the position of an advocate. They adopted the line of being tar advocates, but I was merely reporting the results of my experience. I am not an advocate for either tar, concrete or bitumen, but I merely gave notes of my observation of the results of tar under Delhi conditions. With regard to the first question which Mr. Bashiram raised, we have used No 1 and No. 2 tars—No. 1 for first coat and No. 2 for second coat. In fact we have been guided—as I think most Public Works Department, Municipal and State engineers are always guided—by the specifications put out by the people who sell these materials, and thus as closely as our organisation and our staff permitted we have kept to the specifications which were suggested. From the point of view of my early experience in the Central Provinces I rather agree with the suggestion that consolidation as practised in Delhi—I mean water bound consolidation—is not to a perfect standard. We do not do any appreciable amount of dry rolling as is done with the tough black basalt and with the hard blue lime-stone and other similar stones found in the Central Provinces. It had been my practice in the past to send a 12 or 10 ton roller for about 10 or 12 or even more runs up and down the road over the dry broken stone before any blinding or watering was done at all so as to get proper interlocking. If that is attempted on the brittle quartzite stone of Delhi it is certain that a much too large a portion will be crushed and reduced to such a small size that it will not stand up long as a road after you have finished off the work. So the system that had been adopted long before I came to Delhi and which I have followed is to consolidate with water and a certain amount of blinding definitely from the beginning. The actual quantity of blinding we are using is one part blinding to $7\frac{1}{2}$ parts of broken stone—450 cubic feet of blinding is used for one furlong, when we are consolidating a layer of $4\frac{1}{2}$ inches of metal on a 12 feet road. We

have been following this method where we had a water-bound surface as our final aim and have continued it. Now we add a paint coat of tar or bitumen. We use what I think is known to most of you as a very tough and very sticky red bajri or moorum. That produces a very hard surface. We leave it for some time after water bound consolidation before any form of tar or bitumen surfacing is done. It is almost impossible to brush that off with a wire brush. At the suggestion of Col. Sopwith we used last year a certain amount of clay which he had described as loam as our consolidating material. This brushes off much more quickly. Using this material we will follow up our consolidation with our first coat of tar or bitumen more quickly in future.

Mr. Bashiram said that he found no mention of tar No. 2 being used in Delhi in the paper. I have not mentioned it in the paper because the paper merely notes on those specifications described earlier. But we have done two coats of tar work on two roads which I have mentioned to Col. Sopwith. The reference to Rs. 6 per 100 square feet is the cost of two coat work. In the first item of my schedule I have explained it. If you read the details given in column 1, you will see that the two coat work was done with Chandigarh ballast. I think this Rs. 6 per hundred square feet is not an excessive cost for two coat work include as it does the cost of bringing the Chandigarh ballast by rail from a considerable distance. Incidentally, I think this disposes of, to a considerable extent, the theory that the Delhi Quartzite is entirely responsible for some of the failures. Failure also occurred with Tar when using this expensive imported stone. There is one more point which I should mention. It is the comparison between the Delhi roads and roads radiating from Delhi. The condition of these roads has been adversely compared with the condition of the same roads a few miles inside, say, the Punjab or the U. P. border. The fact is that the traffic intensity varies very rapidly. There was a very clear instance of this in some figures we got for a road we went over a couple of days ago. The intensity of traffic trails off very rapidly as the road gets further from the centre of the town. We find in Delhi that every branch of a road that radiates from it takes away quite a large tonnage from our traffic dansity, and that I think may well explain why other roads 15 to 20 miles from Delhi can be well maintained by a specification much cheaper and much lighter than one necessary within 5 miles of Delhi.

Mr. Sondhi has given me almost an Accountant General's. audit note on my paper. Frankly I can no more answer it standing here than I could answer an Accountant General's audit note on divisional accounts. I am afraid one point is definite. that I did not attend the Second Indian Roads Congress at Bangalore, and I am afraid I have been so remiss as not ot have read all its proceedings. I will, if I can have it put up to me, recast the figures before my paper goes to print in the proceedings so as to make them fit in with the standard laid down. If that had been pointed out to me earlier, I might have corrected my figures.

With regard to light traffic, I mean 150 tons per yard width of mixed traffic, naturally if it is only motor traffic the amount of traffic classed as light would be higher, but we do not get that condition in most places in India. I don't follow Col. Sopwith's remark about "only being 50 tons per yard width per day of bullock-cart traffic". It was apparently a reference to my own note earlier in which I said something about the proportion of bullock-cart traffic. In Delhi, roads take very much more tonnage as they carry heavy bullock-cart and motor traffic. The particular roads under reference are the Rohtak Road and the Muttra Road, both of which carry heavy traffic in

bullock-carts loaded with bricks. I may say with regard to the grading of stones, a point which Col. Sopwith emphasized, that we have attempted in Delhi very careful grading—first screening the whole stone into 3 or 4 grades and then mixing them afterwards in certain proportions. This adds enormously to the expenditure As far as I could judge it did not add very materially to the life of the carpet. It was attempted with considerable care in order to get properly graded material. We tried to get the best possible grading of stone. At the Inaugural Indian Roads Congress I strongly advocated the use of sand as I found it successful in Delhi. There is no doubt in my mind that a bitumen or tar concrete requires sand just as a cement concrete does. It makes a really dense job of the mixture.

With regard to trackways I do not know if any of you went over them when you were at Delhi this time. I think it is really noteworthy how successful they have been on a short length of railway feeder road. This length carries quite heavy traffic. It is obvious that quite heavy bullock-cart traffic was carried throughout the monsoon last year without any perceptible dimunition. I don't think the scheme of filling a slight depression in such tracks with any form of bitumen or tar fill is practicable. The bullock-cart wheel cuts through any such fill absolutely at once. We found serious deformation within a fortnight, and in most of them nothing was left. Straight forward cement concrete tracks have been a very definite success.

Rai Bahadur Chhuttan Lal (Chairman):—Gentlemen, it is not necessary for me to summarise the discussion on this paper. You have heard Mr. Dean's able remarks and also other speakers. Most of the discussion has centred on the experience of tar in Delhi Province. There is no doubt that the general experience of Delhi Province with regard to tar does not conform with the experience of the United Provinces or the Punjab. Of course, so far as the United Provinces are concerned we have still an open mind. We do not say that tar as a painting material is wholly unsatisfactory. In fact, opinion is now veering round to the other side, and it is believed that at certain stages, especially in the initial stages, tar is likely to serve very good purpose.

There is one remark that Mr. Dean has made as regards the specification of the consolidation of stone metal. He said that on account of the brittleness of the stone that is available in Delhi it is not possible for them to follow the standard specification. Well, in Meerut we have been using the Delhi stone and the Delhi grit, and we have found no difficulty in following the standard specification in consolidating our metal. We have used tar also in one or two places and the results have not been unsatisfactory. With these remarks I close the discussion on this paper.

CORRESPONDENCE

Reply by the Author (Mr. A. W. H.) Dean to the comments made by Mr. R. L. Sondhi.

With regard to the remarks by Mr. Sondhi on Traffic Density, I have to explain as follows:—

Traffic density:—The traffic density given in the tabular statement for mile 3 furlong 4 of Delhi-Rohtak Road as 341 tons represents the village cart traffic only, vide remarks in column 7. The figure of total load was omitted but can be added now. It is 772.9 tons.

Similarly the figure given for the G.T. Meerut Road as 571 tons represents village cart traffic only, the total load being 1282.5 tons, as was given in the Delhi Traffic Census paper.

The variation in the figure for the two other roads namely, G.T. Karnal Road and Delhi-Muttra Road as compared with the figures given in the Delhi Traffic Census paper* is due to the points at which the Census was taken being different. The figures given in the statements are for miles 3 and 6 respectively against mile 4 and 7 of the Delhi Traffic Census paper.

The figure represent all kinds of traffic passing the above points.

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*Paper No. 14 in the Proceedings of the Second Indian Roads Congress, Bangalore, January 1936.

Second Day, Tuesday, February 23, 1937.

CHAIRMAN—MAJOR W.B. WHISHAW, O.B.E., M.C., R.E.

Chairman:—I call upon Professor Raja Ram to present his paper.

The following paper was then taken as read.

Paper No. 33

ROADS AND PUBLIC HEALTH IN INDIA WITH SPECIAL REFERENCE TO MALARIA, BORROW PITS, AND ROAD DUST.

By

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Engineer to the Malaria Survey of India, Delhi.

Introduction.—In the early period of the history of 'genus homo', when conditions of life were comparatively primitive and simple, it was possible for individuals and communities to maintain a high standard of health without the guidance and aid of medical, public health and other specialists. But the rapid growth and development of science and industry and their application to human affairs have created so-called artificial or more organised and highly complex conditions of life, which in their turn have resulted in new needs and new dangers; these now call for the active co-operation and assistance of various specialists for their successful handling.

It has thus come about that the work of even road engineers, the construction and maintenance of roads and allied structures needs now to be co-ordinated with that of medical officers of health, public health engineers and other specialists to satisfy the demands of public health. This consideration forms the genesis of this paper.

It is obvious that the primary business of road engineers, in fact all engineers, is to execute their projects in the cheapest possible manner consistent with the quality of work demanded on the basis of sound engineering practice. In doing so road engineers may not in the past have considered the possibility of harmful results accompanying or following in the wake of their new constructions. In many instances road engineering works have thus created and are creating grave menaces to public health. For removing such menaces subsequently, much larger sums of money may be required, if proper precautions are not taken in the first instance. It is obvious that a little increase in initial expenditure based on a knowledge of the essentials of public health principles, would save large expenditure on remedial measures at a later date.

How new road construction can cause the spread of diseases.—The principal menaces that can be and have been created by new road construction are due to :—

(*i*) collections of rain water in borrow pits and depressions which act as breeding places for malaria carrying anopheles, and stegomyia fasciata—the carrier of dengue and yellow fever, and filaria.

(*ii*) dampness in the soil of road embankments which can facilitate the breeding of Ancylostoma duodenale.

(*iii*) collections of road metal on both sides of the road which sometimes act as breeding places for sandflies which cause sandfly fever.

and (*iv*) the dust nuisance, which under certain conditions causes diseases of the respiratory organs, such as bronchitis, pneumonia, tuberculosis etc.

It is proposed to consider in this paper in some detail how road engineers can help in the reduction of causes which produce the type of diseases mentioned above. The first thing to be discussed is the type of road responsible for a large amount of sickness. Road engineers are well aware of the fact that there are metalled roads in India whose milage is comparatively small and earth roads whose milage is by far the greatest of any type of road. The Pucca or metalled road needs no lengthy treatment here, but the earth road, which has several features to commend it for ordinary country traffic needs brief reference.

Earth Roads.—The special advantages of earth roads are :—

(*i*) low initial cost,

and (*ii*) low maintenance charges and suitability for ordinary country traffic; but they also ordinarily possess serious disadvantages,+ some of which can be avoided.

The disadvantages are that they receive very little attention in maintenance and are generally allowed to fall into dis-repair. In most cases they are the original village tracks, but often, where in embankment, they have been extremely badly built, and are in consequence liable to damage by flood. They are badly drained and badly aligned and sometimes are not made to serve the area in the best possible manner. Lastly they are often provided with an inadequate number of culverts and bridges. The absense of all engineering skill possibly points to embankments thrown up as village works in a famine, but the menace to health is there and the attention of engineers cannot be drawn to a better example of what to avoid.

Alignment.—Roads and highways all over the world have to be aligned from considerations not primarily of engineering convenience. The engineer must follow not the watershed but the dictates of transport requirements and most roads have had to be built across the natural drainage system of the areas which they traverse. In low-lying alluvial plains roads must be raised above the general level of the surrounding country so that traffic may move on a dry surface during wet weather. This necessitates the construction of embankments which often tend to obstruct the drainage and raise still higher the level of sub-soil water which in the ordinary course during the rainy season, rises high in the plains of India. Although the damming up of accumulated storm water by embankments takes place only during the monsoon, the water lies long enough to facilitate the breeding of mosquitoes. Anopheles and other mosquitoes breed profusely in many places in such water, and spread the diseases mentioned before.

Bridges and Culverts.—It is a well known fact that the inadequacy of bridges and culverts causes the accumulation of water referred to in the previous paragraph. The number of such outlets should vary according to the rain fall and gradient, the principle being that the storm water should be removed from the surface and the roadside before it has time to soak in and form pools. An average distance between culverts is said to be about 400 feet or say 12

+See U. S. Department of Agriculture "Public Roads" for January 1930 and November, 1931.

culverts per mile. Road engineers will admit that there are not many roads in India which have this number of culverts for their drainage. The result is that one finds during the rainy season vast expanses of water collected on either side of the road embankments stretching for miles and acting as breeding places for disease-carrying mosquitoes. Unfortunately for road construction in India, it has frequently been the case that funds allotted have been limited. This has created a tendency to effect savings by omitting culverts and small bridges, resulting in bad drainage and the spread of mosquito-borne diseases. This legacy of the past, besides being costly in sickness has resulted in increased maintenance charges for badly drained roads. It is suggested, therefore, that a detailed reconnaissance should be made of all existing roads under flood conditions to find out exactly how far the drainage is defective. New and larger culverts, major and minor bridges, intercepting drains, the cutting away of high ground and the construction of retaining walls with an adequate number of weep holes of suitable type are some of the items of work which, if provided, may not only reduce maintenance charges but also contribute to the improvement of the health of the community.

A few of the more common defects noticed by the writer in the design and siting of culverts might not inappropriately be mentioned here. All engineers will remember the culvert constructed with its invert too high above the bed of the water way, with the inevitable pool of water up stream; and the culvert with invert too low and a pool of water down stream. The cost of the necessary structural alterations would not be great but anyway the pools could be filled in at small cost. Then there is the syphon with the non-return flap that no longer closes properly. It was meant to keep out mosquitoes but now provides them with an ideal breeding ground. Drainage syphons in towns should be avoided.

Drainage of land adjoining embankments:—To prevent the accumulation of rain water during the monsoons by road or railway embankments it is necessary to provide efficient drainage of the land on either side in addition to the adequate number of bridges and culverts advocated above. Where the natural slope of the land is inadequate the problem is difficult of solution at moderate cost, but there are many localities where the work could be done quite cheaply and would be done if the engineer would only realize the grave consequences of leaving matters as they are. There are other localities where road lands should be drained at almost any cost.

Drainage of Masonry Structures along Roads.—In many important areas, deep storm water drains with inverts deep below the ground surface running parallel to, or across the alignment of roads are made of masonry. Such drains usually have no weep holes on either side. The omission of these weep holes in some cases causes the rain water during the monsoons, to dam up on either side of the drain. It is prevented from finding a suitable outlet and tends to wash away the earth behind the drain and the masonry is liable to collapse in the course of time, the practice also tends to raise higher the rising subsoil water level during the rainy season. Such conditions create facilities for the breeding of mosquitoes. All masonry revetment and retaining walls along a cutting on the road side, if not properly drained through weep holes or in some other suitable way, are likely to hold up water in a similar manner. It is, therefore, imperative that weep holes of adequate size and at proper distances apart or some other method of drainage should be provided in masonry structures within a mile of habitation along road sides. But the weep holes must be properly made and they should be given the necessary slope to prevent water collecting in them, otherwise drainge weep

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holes may themselves act as breeding places for mosquitoes. Furthermore, weep holes within a mile of habitation should be inspected every year before the rainy season to see if there is any choking up or if they remain wet.

Borrow Pits :—Borrow pits have often to be made along the sides of roads for supplying earth for road embankments. If they are made shallow and are properly drained, they are easy to control. But it is not an uncommon thing to find deep and undrained borrow pits which collect rain water and act as a breeding place for disease-producing mosquitoes. Within a mile of towns and habitations, where bank formation is required for road construction, the earth for the bank should, as far as possible, be taken off from the surrounding ground in thin slices, so as not to leave any hollow or a pit for the collection of rain water. If possible the earth should be obtained from high ground and it is obviously preferable to spend money on extra lead than on anti-malarial measures after the damage has been done.

If borrow pits more than a mile away from the town are made deep, they may act as breeding places for mosquitoes, but are not likely to prove troublesome to the town, as the range of flight of disease-carrying mosquitoes does not generally exceed a mile.

If, in the vicinity of some towns, deep borrow pits have already been made and if they retain water, they should be oiled or treated with Paris green. As an alternative, pumping the pits dry with manual labour pumps, may prove a practicable proposition where such pumps exist and is mentioned for what it is worth.

The writer feels he cannot too forcibly bring to the notice of engineers the short sightedness of subordinating every consideration to economy in the project in hand. There have been projects for road and rail embankments within or in the neighbourhood of populated areas when the cost of leading earth and of digging borrow pits has been estimated and the cheaper alternative has deliberately been chosen. A typical example is found in the Agra-Delhi chord railway embankment at Delhi which is surrounded by numerous borrow pits.

Protection of road staff from malaria.—Long stretches of roads run across malarious and unhealthy tracts in India. For the convenience of engineers and other supervising and inspecting staff as well as for the public, Inspection bungalows, Dak bungalows and Rest Houses have been built on the road side but mosquito-screening has not often been provided in these bungalows. The official on tour and the experienced traveller carries his mosquito-net with him, but in highly malarious tracts he needs protection even in his waking hours. The cost of wire gauze screens to doors, windows and clerestory windows may be considerable, but this protection is his due. The wire gauze recommended for screening is of 14 mesh at least and of 28 to 30 S. W. G. wire, giving apertures of about 0.055 to 0.057 inch.

A plea must be put in for the humble road gang coolie. He is provided with gang huts, at intervals along the road. The cost of screening those huts in malarious tracts would not be prohibitive. As an alternative cheap mosquito-nets may be provided, one half of their cost may be paid by the Road Department and the other half deducted from the wages of coolies.

Dampness and Sandfly fever.—In the earlier part of this paper it was mentioned that the second source of danger to public health from new road construction and road maintenance was dampness in the soil near road embankments due to improper drainage. This danger can be obviated in

exactly the same manner as the first one namely, the collection of water. The third source of danger, sandfly fever, can be avoided by covering up with earth the collections of road metal within half a mile of human habitation. This will prevent the breeding of sandflies.

Road dust and public health in India.—The danger to public health from dust remains to be considered. It may be mentioned that no serious injury to the respiratory mucous membranes results from ordinary road dust if it is free from bacteria. When the dust is excessive or is of an irritant nature or contains pathagenic germs, it becomes injurious. The danger from dust becomes greater if it is constantly present and individuals are susceptible to such diseases as the dust ingredients are likely to induce.

Dust can directly irritate and inflame respiratory organs and indirectly act as a predisposing medium for many infectious diseases. Silica in the dust is a direct irritant and predisposes individuals to pulmonary tuberculosis and induces fibrosis. The presence of pollen, organic matter and bacteria in the dust makes it more dangerous. The common diseases produced by dust due to direct irritation of the mucous membrane are silicosis and asbestosis. To keep down dust on roads necessitates first of all the construction of a proper and good surface. Unfortunately in India road engineers are short of funds and the question of dust prevention on roads has not yet received serious consideration. It is true that recourse is being had more and more to bituminous paint for road surfaces, but this is being done to effect economy; dust prevention comes in only by the way. For dust prevention, as road engineers are well aware, many methods are adopted such as the use of bitumens, asphalt, tar, road oils and solutions of calcium chloride.*

But under present conditions in India the prevention of dust nuisance in towns and villages is a problem admitting of no obvious and practical solution. Even if road surfaces are treated with bitumen or oil there is in busy thoroughfares the dung of draught horses and bullocks to be dealt with. In busy quarters hundreds of tongas ply and the horses invariably drop dung. Before it can be swept away it dries in the hot sun and is converted by the wheeled traffic into dust of a dangerous kind. Another source of dust is the Kuchha courtyard of houses on either side of the road. The sweepings from these courtyards are usually thrown on to the roadside and are a source of the dust nuisance. Unless the houses have *Pacca* courtyard and motors replace draught animals the dust nuisance must continue. It is a well-known fact that dust storms and clouds of dust wafted from the deserts of Rajputana overcast the sky during the dry season. Thus the dust nuisance cannot be prevented by even cement concrete roads and asphalt surface treatment when such other formidable sources exist. But coming to the prevention of the dust nuisance from the road surface itself the precautions mentioned above should certainly be adopted. The matter is receiving some attention in large cities but a plea may be put in for the village through which a public highway passes. The treatment of quite a short length of road would prove of immense benefit to shopkeepers and dwellers in houses on the road side.

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*See 1. W. V. Piotrovski—Petroleum. Zeitschrift. 1929, 25, 260, Dust Prevention on Roads
2. F. Zeckel—Architect, Bautech. 1933, 20 (19) 160-1 Dustless Road Surfaces.
3. K. Schmeiger.—Strassenwesen 1936, 9 (6) 71 Road Oiling in Vienna.
4. U. S. A. Agriculture Year Book 1907 Dust Prevention.

Moreover the dustless surface should be sufficiently wide to keep vehicular traffic off the earthen berm. A cheap and efficient form of widening is a brick on edge pavement and the ideal width for this pavement is from the edge of the treated surface to the side drain. This incidentally helps drainage and prevents the formation of unhealthy muddy margins in wet weather.

Recently a mixture of molasses, water and phenol has been mentioned as having proved effective, as a dust preventive on a certain private estate but experience was based on a trial of only about 3 weeks. Without considerable trial on public roads, no useful opinion can be expressed on the merits of the new process. Further in Mysore State molasses has been used to provide a smooth and dust free surface and to protect the underlying macadam from wear. Even this experiment is of too recent a date to warrant a pronouncement of opinion, and these two departures from normal practice are only mentioned to show that engineers have not been backward in attempting to utilize an abundant by-product of the rapidly developing sugar industry.

Conclusion.—To avoid any impression of captious criticism divorced from reality as represented by the limitations of the public purse the writer would repeat that the range of action of the mosquito is a mile. Such funds as are available for remedying the errors of the past need not, therefore, be spent outside the radius of a mile from towns and villages. New borrow pits unless properly drained should not be dug within this distance and care in the preparation of new projects would then provide the additional security asked for.

But so far as malaria and other mosquito-borne diseases are concerned, the writer must sound a note of warning to engineers against the indiscriminate or misguided adoption of anti-malarial and public health measures in any locality. A malariologist or public health officer should always be consulted before any such measures are adopted. It is a common belief amongst lay people that anti-malarial and anti-mosquito measures are synonymous, but it is not quite so, for it is only about half a dozen out of about 43 species of Anopheles found in India that act as malaria carriers. Out of the malaria-carrying Anopheles, *A. maculatus, A. minimus* and *A. Sundaicus or ludlowi* prefer breeding places exposed to sunlight so that if these species are found in a jungle, the indiscriminate clearness of that jungle, as happened in Assam, would help their more profuse proliferation, though it will be deterrent to the breeding of the shade loving *A. umbrosus.* Salt swamps in India, Burma and the Andamans are the favourite haunts of *A. ludlowi.* A thorough knowledge of the bionomics of various species of Anopheles and other mosquitoes is the most important factor in the campaign for the eradication of malaria, and therefore engineers should, when necessary, consult the malariologists or entomologists who possess such knowledge.

The writer considers it desirable that at least one assistant engineer in each division of the buildings and roads branch of the P.W.D. in malarious and unhealthy tracts and provinces, such as the Terai and Bhabhar estates, the northern slopes of Khasia Hills, West of Chota Nagpur in Bihar and Orissa, the foot of Nilgiris, Dooars, Singhbhum, the Agency Tract in Madras Presidency Eastern Ghats, etc., should be deputed to undergo a short course of instruction and training in the special aspects of engineering relating to malaria and public health. Though by undergoing such a course of instruction, an engineer may not become an expert malariologist or Public Health Officer, he would at least learn to appreciate the damage which many ill-executed (from the sanitary point of view) projects may cause. He should also be in a position to avoid

blunders in the future. He would be capable of carrying out minor anti-malarial operations, and engineering works for the improvement of public health on his own initiative, and would realise the necessity of obtaining expert advice from the malariologist or Public Health Department on major works. In short it is high time for road engineers, in fact all civil engineers in India to realise that the eradication or control of all mosquito-borne diseases including malaria is as much an engineering project as it is a sanitary or a medical problem.

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DISCUSSIONS ON PAPER No. 33.

Professor Raja Ram (Author):— Mr. Chairman and Members of the Congress.—In the first place, I want to thank the Council of the Congress for permitting me to read the paper, for as you are aware I am not a member of the Congress. This paper was written at the instance of the Public Health Commissioner with the Government of India under whom I am temporarily placed. The Health Department of the Government of India has for a considerable number of years been acutely feeling that the various branches of the Public Works Department in India have been in many instances inadvertently building works in such a manner that they have caused and are causing a large amount of preventable sicknesses. All the attempts of the Health Department in the past to persuade engineers to attend to certain broad considerations and principles of Health preservation in their projects and works seem to have gone generally unheeded, until the work or project itself could not be executed owing to sickness among labourers as happened at the Headworks of the Sarda Canal. One of the most harmful and common disease engendered or its incidence substantially increased as a result of some of the works executed by the Public Works Department is Malaria. Evidently disappointed by the scanty response of the Public Works Department engineers, the Health authorities in order to press their point of view got the following resolutions passed at the Business meeting of the Seventh Congress of Far Eastern Association of Tropical Medicine

held in British India in December 1927, which laid stress on Man made malaria. The first resolution reads as follows:—

"The Malaria section of the Seventh Congress of the Far Eastern Association of Tropical Medicine are aware of many instances of a great increase in the incidence of Malaria caused by the facilities given to mosquito reproduction by engineering works, either during construction, or afterwards, due to the different conditions brought about. This Congress is of the opinion that plans for railways, canals, harbours, and all similar engineering works likely to affect the conditions producing malaria, should be submitted to the proper public health authorities, and their sanitary engineers before being sanctioned by Governments."

They passed a second resolution which reads as follows:—

"For wide rural areas, specially those with scanty, poverty-sticken populations the first step in the control of malaria is adequate research, so that the conditions present may be ascertained and the best methods of control under the particular circumstances ascertained as a result of research. Methods of prevention may be of great variety, and include drainage, flooding, jungle clearing, jungle preservation, bonification, the promotion of agriculture, improvement of housing and the general economic condition, education etc., of the people. The systematic killing of the adult mosquitoes-screening, the use of anti-malarial drugs, and a host of special methods have each to be considered in their proper application. The Congress desires to stress the need not only of thoroughly trained malaria research officers, but of expert malarial engineers in whichever type of malaria prevention is at stake"

In pursuance of the recommendations embodied in the last sentence of the second resolution, the Indian Research Fund Association selected me for appointment to the post of Malarial Engineer to the Malaria Survey of India. I joined this post on July 2, 1934, and under the guidance of two very able Directors of Malaria Survey of India Lt.-Col. Sinton, D.Sc., M.D., V.C., I.M.S., and Lt.-Col. Covell, have been able to see for myself where the engineers were found wanting from the Public health point of view. Some of these observations based on extensive tours through various parts of India are presented before you in this paper.

Personally, I feel that engineers can help materially in the control of malaria and some other diseases in India. Le Prince and Orenstein, the two eminent engineers, in Panama, by their public health work in the prevention of Yellow Fever and malaria made the construction of the Panama Canal a practical proposition. Owing to the incidence of these diseases the construction of this very canal by a French Company was made previously impossible. Henry Home, Hardenburg and Evans are other engineers of note in the domain of malaria prevention and control in other lands than ours

In dealing with engineering measures for the control and prevention of mosquito-borne diseases some further explanation may, I believe, prove useful. Firstly, it is obvious that if there are no mosquitoes (*i.e.*, the carriers of the diseases) there will be no sickness caused by their bite.

All anopheles and most culicines breed or lay their eggs in water. Anopheles develop from the egg stage to adult stage in 6 or 7 days under ordinary conditions of weather, culicines take from a week to seven weeks and sandflies from 2 to 5 weeks. If engineers can arrange in all their works under and after construction not to hold up water, except where it cannot be helped, for more than six days there can be no breeding of anopheles and culicines, and therefore

no mosquito-borne diseases. If water is held up for more than this period it should be treated with oil, Paris green, pyrocide or other insecticides. For removing water an efficient and well-planned system of drainage is essential. One thing more should be remembered and that is that anopheles always breed in comparatively clean water whereas culcines breed even in sewage offluents. Even one-eighth inch deep water of the size of a rupee is sufficient to enable hundreds of mosquitoes to lay their eggs and breed. The next point of importance is the limit of distance from habitations for effective anti-malarial control measures, in other words how far from inhabited areas should there be no standing water for the prevention of malaria and mosquito-borne diseases generally. So far as our present knowledge goes a minimum distance for control works is one-quarter of a mile right round populated places, preferably one-half of a mile; under ideal conditions where money is no consideration it may be extended to one or one and a half mile, for the range of flight in the case of culicines is from one to two miles. Among other measures the road engineers might consider the feasibility of mosquito-proofing of wells, water cisterns and dak bungalows on the roadside in malarious tracts.

If all engineers including road engineers applied themselves to a study of the problems of public health in relation to their specific branch of engineering and if the Government and their chief engineers encouraged them to do so and apply the results of their study in the execution of works I feel certain that the lead for controlling preventable diseases by engineering measures will pass from the hands of medical men to those of the engineers. It may be worthwhile mentioning that the first enquiry into 'Malaria and water-logging' appointed in India by the British Government, *i.e.*, the East India Company was in 1847 and consisted of three members of which Major W. E. Baker (President) and Lt. Yule were Engineers and Surgeon T. E. Dempster was the only medical man. I think that should represent the correct proportion of the activity of the Engineering and Medical workers in the domain of such Malaria control activities.

I am primarily concerned with malaria. However at the instance of the Public Health Commissioner I have also dealt with dust nuisance in my paper and in this respect having no practical experience of the subject, I have done as best as I can. If there is any point which requires further explanation I should be glad to explain it.

Mr. N. Das Gupta:—I agree with Professor Raja Ram regarding the care that should be exercised in digging borrow pits near human habitation, but I doubt whether it would be possible to take out earth in thin slices when the embankment to be made is high. I would rather follow up the method adopted by the District Board of Dacca for making embankments near human habitation. Instead of digging a number of borrow pits along the aligument they acquired the old stagnant ponds of the village through which the road passed and from which the necessary amount of earth was dug out. Thus the villagers instead of having borrow pits full of mosquitoes, have now got several big tanks from which they can get plenty of water all the year round. I think this is a move in the right direction and engineers in charge of similar works instead of achieving their own ends at the cheapest way should also keep their eyes open to the welfare of the people of the villages through which their road runs.

Chairman:—I call upon Professor Raja Ram to reply.

Professor Raja Ram:—In reply to the question of mosquito-proofing of wells, I think it will be better for me to refer to the general principles of

mosquito-proofing. I have recently contributed a paper on, "The design of mosquito-proofed buildings in India" which has been published by the Institution of Engineers (India), and to those of you who wish to look at it I can lend my copy. As regards mosquito-proofing, the main principle is that we should leave no apperture in any building or structure larger than the size which can admit a mosquito into it. This means we should cover up the wells entirely, provide slabs over them and put in either a hand-driven or a motor-driven pump. I have prepared some designs for Delhi area and I have got them at my Delhi office. They are not very elaborate but they give the essential features of the design and I shall be very glad to supply copies of these designs to any member who would like to see them.

Mr. S. G. Stubbs (Punjab):—What about the well with a Persian wheel.

Prof. Raja Ram:—We cannot mosquito-proof it. Only those structures which are capable of mosquito-proofing can be mosquito-proofed.

Chairman:—On behalf of the Congress I thank Prof. Raja Ram for his very interesting paper covering a subject which we as engineers are somewhat apt to overlook or neglect.

I suggest that if his paper will induce more of us to prepare estimates in such a way that we can finish our works satisfactorily in respect to the kind of details that he has mentioned, his paper will achieve one very useful result; and if it will induce any of us to try and do something to fill up borrow pits along the sides of roads—even if it be on a ten year plan—and so make an alternative way for animals and pedestrians, it will have served another very useful purpose.

CHAIRMAN—Brigadier E. C. Walker.

Chairman:—In the absence of Mr. G. L. W. Moss, I call upon Mr. J. P. Anderson to introduce the paper.

The following paper was then taken as read.

Paper No. 36

WAYS AND MEANS OF IMPROVING THE BULLOCK-CART.

By

G. L. W. Moss, Service Manager, The Dunlop Rubber Company (India) Ltd., Calcutta.

Bullock-carts, as they may be seen in India to-day, are probably very little changed in design and general appearance from the bullock-carts that were to be seen many hundreds and even perhaps thousands of years ago. The circumstances and conditions in which they work have, however, changed immeasurably.

Modern communications have so stimulated industrial development in and around the larger towns and cities, and agriculturally have resulted in so great an extension of the cultivation of 'money' crops as opposed to 'subsistance' crops that entirely new Transport and Traffic problems have been created. In

the highly industrialised countries of the West the mechanization of transport has proceeded at a rapid rate. In India, however, the vast undeveloped areas with their inadequate roads, coupled with the extreme poverty of the agricultural population, ensure the continuance of Animal Transport for many years to come. The Government of India Census in 1930 returned the number of bullock-carts in India at approximately $8\frac{1}{2}$ millions, and there seems to be little evidence of any diminution of their numbers.

Although a great deal of independent experiment is of course always being carried on by various Road Authorities, it is perhaps somewhat surprising in view of this vast traffic that an authoritative and comprehensive investigation into the effects of Bullock-Cart Traffic on various modern Road Surfaces has not already been carried out in this country. Opinions regarding the time required for the destruction of certain types of surfaces by various intensities of Bullock Cart Traffic differ very considerably, but there is ample general testimony to the prowess of this Iron-Tyred Traffic for the job. In this connection the Consulting Engineer to the Government of India (Roads) in the March 1933 issue of 'Indian Roads' remarked :—

> "There is general agreement regarding the destructive action of many Bullock-carts upon road surfaces and this has come prominently to notice in recent years owing, firstly to the destructive effect of combined motor and bullock-cart traffic on macadam roads and, secondly, owing to the way in which tracking bullock-carts cut through certain asphaltic surfaces which are quite suitable for heavier mechanical transport units".

Experiments carried out in Brunswick some years ago on the Brunswick Experimental Road demonstrated that of all classes of traffic the greatest damage was caused by mixed rubber and iron-tyred traffic, and it was reported that 82,500 tons of mixed tyred traffic caused more damage than the 820,000 tons of rubber-tyred traffic operating at much higher speeds. The iron-tyred traffic for these tests was provided by mechanically drawn trailers and therefore probably properly sprung, and fitted with very much superior hub and tyre equipment than that ordinarily possessed by the Indian Bullock-cart.

The Seventh International Roads Congress held at Munich during 1934 in an 'Investigation of the relationship between vehicular traffic and road surfaces in regard to the economy of transport' concluded that :—

> "The greatest difficulties connected with the adaptation of the surfaces to the traffic are encountered when there is a mixed traffic consisting of rubber-tyred motor vehicles and iron-tyred horse-drawn vehicles. The lighter the form of construction the greater are the difficulties, which do not rise to any noticeable extent in the case of heavier forms of construction.
>
> In view of the use of draught animals, owing to their shoes being frequently fitted with grips and calks, and in view of the utilisation of iron-tyred vehicles, it will, in many cases, be more economical to make use of heavy forms of construction, even though the motor vehicle traffic may be comparatively small".

(Conclusions 7 and 8) (5th question)

A good example in India of the effect of heavy mixed rubber and iron-tyred traffic is provided by the Lady Jamshedji Road in Bombay which although having a carpet of 3" asphalt on a 6" cement-concrete foundation is yet

worn into deep ruts, which are irreparable except by renewing the carpet at a heavy cost. On the other hand, Queen's Road of the same city, on which bullock-cart traffic is prohibited, has a surface of only ½" asphalt dressing on an ordinary water bound surface, and although subject to a high intensity of motor traffic, costs very little to maintain. Similar evidence of the damage wrought by heavy cart traffic is to be seen in almost every large town.

Mention may be made here of some experiments carried out in New Delhi by the Public Works Department in 1935*—to determine the relative effect of iron-tyred and rubber-tyred carts on an asphalt painted road surface :—

"Each cart carried 500 bricks or approximately 3,500 lbs. The pneumatic tyred cart had two wheels with a track of 5 feet 6 inches, the weight of each wheel when fully loaded being 18 cwts. and it was drawn by one bullock. The wheels of the local cart were, rear 3 feet, front 2 feet in diameter. The tyres on all four wheels were 2½ inches wide, the wheel base was 4 feet 6 inches and the track 5 feet. The loads on each wheel when fully loaded were front 7 cwts., rear 13 cwts. The cart was pulled by a pair of bullocks.

Both carts were set to circulate on an asphalt painted road 40 feet wide, their tracks being marked out for them and consisting of two strips of 100 feet each way with semi-circular ends. After 1,400 circuits the painted surface under the local cart started to break up in small patches, and after about 30,000 circuits the surfacing of the track under the local cart was practically destroyed, while that under the pneumatic tyred cart showed no signs of wear. It was then calculated that the damage done by a local four-wheeled cart of this type for that part of its trip for which it was loaded would amount to Rs. 57/- per annum for every mile of daily travel, while the damage done by the pneumatic tyred cart was imperceptible, or in other words that the cost of maintenance of a mile of road of this type used daily by 100 local carts would be Rs. 5,700 per annum".

Similar tests were carried out in the same year in the North-West Frontier Province under the direction of the Director of Agriculture & Allied Allied Departments, and were described as follows :—

"Two ring tracks 9 feet wide and 369 feet in length were laid down. The construction consisted of:—

6" of soiling with 2½" metalling. Surfacing with Colas on one half and Tar on the other. Consolidation of soiling and metalling with heavy roller.

On one ring two country bullock-carts were placed. The weights of cart and load were 4,727 and 4,851 lbs. in each case.

On the other ring two rubber-tyred carts were circulated the laden weights of which were 7,258 and 6,763 lbs. each.

The track on which the country carts were plying showed immediate signs of wear, and in the course of four days had worn into deep pot holes.

In spite of continual repairs the wear did not abate and after 19 days (for the first six days the test was carried out with single carts) during

*See 'Indian Roads' October 1935 issue, page 3.

which the test continued for 8 hours a day, the experiment was given up as it was thought that the tracks must have been badly laid. The ring on which the rubber-tyred carts were circulating showed practically no signs of wear.

The average pace of the rubber-tyred carts was 3.12 m.p.h. and of the country carts 2.61 m.p.h.

It was then decided to carry out the tests on the Grand Trunk Road between Peshawar and Nowshera. This is a bitumen emulsion treated road on which 50 years of consolidation has been going on.

The stretch chosen was resurfaced in July 1934.

Two lengths of 110 yards were chosen and the same country carts and rubber-tyred carts were driven up and down for 8 hours a day.

The ordinary traffic was diverted to the side.

On the fourth day the tracks on which the country carts were circulating began to show signs of wear and in patches the surfaces began to peel off".

These experiments illustrate the enormously destructive effects of bullock-cart traffic on metalled roads and enable some idea to be gained of what it must cost the country on road maintenance charges.

On rural Earth roads the effects of iron-tyred bullock-cart traffic are not perhaps so serious from the point of view of Road maintenance costs, as from the economic aspect of bad communications resulting from the deterioration of road surfaces. It is indeed not uncommon for whole areas to be completely cut off from all contact with the outside world for a considerable part of the year, owing to the impassable state of the roads as the result of bullock-cart traffic. In this connection tests carried out by the Imperial Institute of Agricultural Research, Pusa, are interesting.

*"Experiments detailed here have already shown that in the course of 664 journeys made by ordinary farm carts with a load of 25 maunds cane, and returning empty over an ordinary kuchha cart track or *likh*, the wear on the *likh* was 3½ inches greater than that produced by a Dunlop cart carrying double the cane maundage working on a similar track and making a similar number of journeys, while that of the ordinary country cart carrying 12 maunds and doing a similar number of journeys was worn down to 4½ inches below the Dunlop surface.

At the bottom of all this is the real crux of the carting problem. The average country cart by its destructive action on the carting surface reduces its own pay load automatically as the season progresses, and does a tremendous amount of damage to the road which has to be repaired before next season, while the Dunlop cart carrying a much greater load maintains its carting surface in excellent condition and by this method keeps its pay load at the same level throughout the season and reduces the cost of road upkeep to the District authorities".

*Page 532, Agriculture and Live-Stock in India, Vol. IX, Part V, Str., 1934.

The Royal Commission on Agriculture refers to the effects of bad communications[1] as follow:—

> "India being essentially an agricultural country, bad communications not only hamper the agriculturist in marketing the produce but also raise the price of his produce and purchases from elsewhere. In fact it has been the improvement in communications generally since the middle of the last century that, more than any other factor, has brought about the change from subsistence farming to the growing of money crops such as cotton, jute, groundnuts and tobacco.
>
> Bad communications also impose a constant strain on the stamina of draught animals and seriously reduce their efficiency for the all-important work of cultivation."

The bullock-cart therefore constitutes a very real problem. It is a vital link in the transport services of the country, and provides the major means of communication for vast areas. It is at the same time one of the most road-destructive types of traffic, and to a large extent regularly immobilises itself and other traffic, throughout a substantial part of each year in those areas where it is most needed.

Turning now to the bullock-cart itself, before referring to some of the ways which have been suggested for improving the bullock-cart, it should be noted that any proposed improvements must be of necessity either cheap enough to be within the reach of the resources of the average bullock-cart user, or must so increase the transport efficiency of the vehicle as to render the improved type attractive to capital, and so make the provision of financial assistance practicable to the more impoverished type of user. Efforts to improve the bullock-cart must obviously be concerned with the hub and wheel equipment. In many parts of the country the rest of the cart merely consists of bamboos, or pieces of timber roughly fastened together.

The majority of bullock-carts operating in and around towns and cities, and large numbers of carts in rural areas now have iron axles and iron tyres. These axles are bedded in a wooden axle tree and terminate at each end in a journal of small diameter, which works in a roughly made iron bush sunk into the wood work of the wooden hub. The wheel is then built up from the hub and an iron tyre fitted over the felloe band. The size of wheels employed varies very considerably, the diameters ranging from 3 feet to 5 feet 6 inches or even 6 feet (except in the case of four-wheel carts where the front wheels are of course much smaller). The design of the felloe band also varies in different parts of the country and it is interesting to note the different widths and shapes of felloe bands that have been developed as the most suitable for easy passage over different types of surfaces. The width of the iron tyre also varies in many parts of the land, and for different conditions of service. Widths range from 1½" to 3"—more or less in accordance with gross axle loads, which run from half-a-ton to as much as 3½ tons. It is not easy to calculate exactly what these loads represent in road pressure per square inch, as it is almost impossible to determine exactly the actual area of contact between an iron tyre and the road surface 'because the elastic deformation of the wheel and the elastic and plastic deformation of the road surface and the layer of dust over it cannot be estimated'. Few roads are sufficiently smooth to give an even bearing between the iron tyre and the road surface and also, as the result of continual screwing over the road, iron tyres almost inevitably wear into a curve and thus produce point loading.

[1] I.R.D.T.A. Pamphlet No. 22.

It has, however, been estimated* that the actual contact area of a country cart wheel with macadam would be about $1\frac{1}{2}''$ to $2''$ and that assuming it is about $2''$ the mean intensity of pressure between the iron tyre and the road must be between 500 lbs. and 900 lbs. per square inch—while the maximum must be considerably greater. When it is considered that in addition to these high static loads the destructive effects of iron-tyred bullock-cart traffic is aggravated by a pulverising action produced by excessive play in the hub, wear of the iron tyres causing point loading, splaying of the wheels and other irregularities—some idea may be gained of the capacity of the bullock-cart as a surface destroying agency.

As against 500-900 lbs. pressure per square inch under the most favourable circumstances of the country bullock-cart wheel, it is interesting to compare the intensity of pressure exerted by the pneumatic tyres on the average bus or truck. The size of tyre in most common use is a $6''$ tyre on a $20''$ rim (32×6) which is suitable for a maximum load per wheel of 2,650 lbs. It is found that the area of contact with the surface of the road is 40.382 square inches at an inflation pressure of 80 lbs. per square inch. This gives a maximum intensity of pressure between tyre and road of 65 lbs. per square inch.

Methods of bridging the gap in tyre efficiency between rubber-tyred and iron-tyred vehicles involve either (*i*) improvements to the existing type of cart hub, wheel and tyre, or (*ii*) the substitution of alternative types of hub, wheel and tyre equipment.

It is only recently that much attention has been given to the former method, and investigations do not seem to have as yet progressed much beyond the experimental stage. It may be remarked, however, that the modifications proposed by would-be improvers of the existing wheel and hub equipment, invariably involve the use of wide iron tyres, four inches to five inches in width, in conjunction with, either roller bearing hubs, or hubs fitted with cast iron bushes. Wide iron-tyred wheels are, if properly made, not only heavy, but expensive to manufacture, and when operated over rough surfaces—costly to maintain. Bullock-carts, as well as operating over metalled roads, as a rule, also have to traverse unmetalled roads, which are often no more than rough uneven tracks. It is very questionable if wide iron-tyred equipment can be produced to give satisfactory draught and maintenance results for such conditions as these. The utilisation of roller bearing hubs for un-sprung iron-tyred wheels, whilst having advantages in the matter of draught, is, however, open to serious objection on maintenance grounds. Further more, owing to the fact that except at high original and maintenance cost, it is impossible to prevent an iron-tyre from wearing and forming a curve—resulting in point loading, the improved efficiency of the wide iron tyre is considerably mitigated. Finally, it is doubtful whether a sufficiently substantial gain in operating efficiency can be secured in this way as to render the improvements effected an economic proposition from the user's point of view.

The second method mentioned above obviously points to the provision of rubber tyres. From the Road Engineer's point of view, the pneumatic tyre is the ideal solution of the bullock-cart problem. Large section pneumatic-tyred carts rolling at bullock-cart speeds, practically eliminate wear on modern road surfaces from this class of traffic, whilst the effect on kuchha surfaces is merely one of steady consolidation.

*See Indian Roads 'Loads and Tyres of Bullock Carts,' March 1938 issue.

Pneumatic equipment for bullock-carts was first introduced some three years ago and has made considerable progress. It is estimated that there are now six or seven thousand pneumatic-equipped vehicles operating in India, whilst very much larger numbers of horse-drawn vehicles on pneumatic tyres may now be seen in England and other countries. The equipment comprises cast iron hubs, each hub being fitted with two taper roller bearings. The wheels are of the steel artillery type and are fitted with specially designed pneumatic tyres. The section of pneumatic tyre in most general use on bullock-carts is an 8" section on a 19" diameter rim. The approximate contact area of this tyre with the road surface, with a load per wheel of 3,925 lbs. at an inflation pressure of 70 lbs. per square inch is about 87 square inches, which gives an approximate average load per square inch of contact of 45 lbs. The difference between this figure and the 500-900 lbs. minimum intensity of road pressure of the ordinary bullock-cart wheel, reveals very strikingly the comparative inefficiency of the iron tyre for road transport purposes. In the case of the experiments, already mentioned, made at Delhi, Pusa and in the North West Frontier Province, it was found that no apparent damage to road surfaces had been done by the pneumatic-equipped carts under test.

Another very important advantage that the pneumatic equipment possesses is that the shock absorbing properties of the pneumatic tyre enable a taper roller bearing hub to be satisfactorily utilised. This hub in conjunction with the pneumatic tyre secures a substantial reduction in draught as compared with the draught of the ordinary bullock-cart. *Experiments carried out in the United Kingdom indicated that the pay load that could be carried for the same draught was always greater than when ordinary wheels were used. The increase in pay load due to the use of pneumatic equipment varying from 35% to 108% according to surface conditions. These tests were of course made with farm carts as used in England and the same farm carts fitted with pneumatic tyres. Similar tests made in this country indicate that the possible increase of pay loads for bullock-carts is much greater, owing to the fact that the hub and wheel arrangements of country carts are much less efficient than that of the average Farm cart in the United Kingdom. The following table† of comparative draught compiled at the Imperial Institute of Agricultural Research, Pusa, is interesting in this connection:—

Description of cart	Weight empty cart Mds.	Cane Load Mds.	Total Weight Mds.	Lb. D. B. P.	Lb. D. B. P. per Md.	Comparative draught
Ploughed land (From chart I)						
Dunlop wooden cart	9.75	25	34.75	112	3.46	100
Dunlop iron cart	13.25	50	63.25	308	4.87	141
Farm cart with iron tyre	10 00	25	35.00	392	11.20	324
Ordinary cart without iron tyre	6.75	16	22.75	280	12.30	355
Country cart track						
Dunlop wooden cart	9.75	25	34.75	48	1.38	100
Dunlop iron cart	13.25	50	63.25	100	1.58	115
Farm cart without iron tyre	10.00	25	35.00	60	1.72	125
Country cart without iron tyre	6.75	16	22.75	80	3.52	255

*Ministry of Agriculture and Fisheries of U. K. Report 56 of 1933.

†Agriculture and Live-stock in India Vol. IX, Part V, Page 530 of 1934.

The results of practical usage in different parts of the country in varying circumstances, amply demonstrate the very substantial reduction in draught secured. One example which may be quoted is that of a leading Municipality whose pneumatic-equipped bullock-carts transport 128 tons of refuse per month as against 35 tons carried by the iron-tyred cart. In the sugar-cane areas of North Behar and the U.P., it is found that the pneumatic-equipped carts are able to transport from 50 to 70 mds. of cane as against the 20 to 25 mds. normally carried by country carts.

Not only, therefore, is pneumatic equipment the ideal solution of the bullock-cart problem from the road engineer's point of view, but it carries with it considerable economic advantages to the user, which apart altogether from other considerations is attracting increasing numbers of bullock-cart operators to pneumatic equipment.

The chief objections to pneumatic equipment are (*i*) The high initial cost of the equipment and (*ii*) The inability of the bullock carter to maintain properly pneumatic equipment. The high initial cost of pneumatic equipment is undoubtedly a serious drawback, although it should be pointed out that when expressed as a rate per maund of pay load capacity, the cost of the indigenous bullock-cart and the pneumatic-equipped bullock-cart is approximately the same—that of a complete cart on pneumatic tyres ranging from Rs. 200/- to Rs. 250/-. It is, however, not always necessary that new carts be purchased as existing carts are readily convertible, and in many cases it is possible by re-arrangement or extension of side supports to increase satisfactorily the cubic capacity of the vehicle. In such an event the cost of complete conversion ranges from Rs. 150/- to Rs. 200/- per cart. This cost is admittedly high, and at present the adoption of pneumatic equipment is necessarily confined to those bullock-cart users with capital or such others as are associated with capital in some way.

The problem of bringing pneumatic equipment within the reach of the general carter should not, however, be insoluble. The general adoption of it would effect enormous economies in road upkeep costs, mean increased earnings or reduced transport costs to bullock-cart users, and considerable business to the equipment manufacturers. It should not, therefore, prove impossible to find some way of bringing these three interests together in a financial scheme to render change-over to pneumatic equipment possible.

The second main objection, *viz.*, the ability of the ordinary carter to maintain properly a set of pneumatic equipment, undoubtedly gives cause for misgiving. It may be remarked, however, that the risk of puncture is slight and the incidence of punctures is probably considerably rarer than that of broken wheels etc., of the ordinary type of cart. The same difficulties regarding maintenance must have been encountered when the motor bus was first introduced, and time and experience will most certainly cure this disability.

As in the case of motor traffic, adequate service arrangements would be likely to follow closely the development of the use of pneumatic equipment by bullock-carts.

Except for the pneumatic tyre, no other form of rubber tyre has been satisfactorily produced for use on bullock-carts—although considerable research work has been carried out to determine the practicability of a solid or cushion rubber tyre for bullock-carts. There are, however, technical and manufacturing obstacles to the production of such an article which, so far, it has not been possible to overcome.

If the present enormous cost of the destruction caused by the bullock-cart traffic is to be reduced in any way, it would seem of necessity to be by way of the pneumatic tyre, and there would thus appear to be a good case for further enquiry into possible ways and means of promoting the use of pneumatic equipment for bullock-carts.

DISCUSSIONS ON PAPER No. 36.

Mr. J. P. Anderson :— Mr. Chairman and Gentlemen.—I would like, if I may, to make one or two brief remarks in regard to this paper. The author has pointed out that any proposed improvements in Bullock Cart Equipment must carry with it a powerful economic incentive to its adoption if it is to have any real chance of success. In other words, unless the Improved Equipment offered can definitely be made to pay from the Bullock Carter's point of view, there would seem to be little hope of any large scale conversion unless by enormously expensive subsidy schemes. Therefore, in considering ways and means of improving the Bullock Cart it is useful to distinguish between the various classes of Bullock Cart Traffic. There are, for instance, vast numbers of bullock carts operated in circumstances that render them practically immune from economic attack. I refer to the hundreds of thousands of village carts engaged only in seasonal transport of local produce from village to village, whilst, during the remainder of the year, men and animals are employed in ploughing, irrigation, threshing, etc.

A large proportion of such carts are not fitted with Iron Tyres, and, to a large extent, operate mostly over village roads.

Another class of Bullock Cart Traffic is that which has come about as the result of the increasing growth of money-crops, such as Sugar Cane, Cotton, Jute, etc., involving transport from over a wide area to a centrally located Mill or Press. Owing to its association with Capital and the pressure of competitive production, this class of rural Animal transport is more open to economic considerations.

There are other categories, but I think you will agree with me that the most important class of Bullock Cart Traffic, from the Road Engineer's point of view, that is the class causing most damage to road surfaces—the Public Enemy No. 1—Roads—is the heavily-loaded Iron Tyred Cart of the professional Bullock Cart Operator, plying in large numbers—increasing numbers in many Districts—in and around and between the Towns and Cities of this Land.

In general this type of regular Bullock Cart Operator is definitely open to economic pressure, and if Improved Bullock Cart Equipment, enabling carting earnings to be increased and expenses reduced, is introduced to him it must, in the nature of things, prevail in the end over the obsolete and less efficient type of Equipment.

Unfortunately, although the Improved Pneumatic Equipment, described by the author in this Paper, provides the requisite increase in the Pay-load efficiency, there are still many obstacles to be overcome before the pressure of the economic advantages inherent in the Improved Equipment can make themselves felt.

There are the difficulties of Introduction,—the inertia and, sometimes, opposition that has to be overcome, and the extreme poverty of many Bullock Cart Operators. There are Legal difficulties arising from obsolete or inadequate laws governing maximum permissable Pay-loads, which, in many areas, prevent any economic advantage being taken of any reduction of Draught that the use of Improved Equipment may provide.

Much could undoubtedly be done to encourage the spread of the use of Pneumatic Equipment amongst the professional class of Bullock Cart Operator by :—

(i) The suitable amendment of Provincial and Municipal Laws governing Permissable Pay Loads on Animal Drawn Vehicles.

(ii) By Government, Public and Muncipal Authorities setting a good example by adopting the Improved type of Cart Equipment themselves through their Contractors.

(iii) By the opening of District Board, Canal Bank and other Roads, at present closed to Bullock Carts, to those fitted with Pneumatic Tyres.

(iv) By consideration by Provincial and Municipal Authorities of schemes of financial assistance where such are practicable.

That is all I have to say. I shall be pleased to endeavour to answer any questions that may be put.

Mr. H. B. Parikh (Sind):—Mr. Chairman and gentlemen.— Mr. Moss has done a great service to the Engineers connected with roads by writing a paper on the ways and means of improving the bullock cart. This question has now come more in prominence owing to the difficulties of adopting the economical types of road construction that will cater both for bullock carts and the fast moving motor-traffic, the destroying effects of which are complementary.

We in Sind are very much interested in this problem. Sind is very backward in point of communications and the advent of the Lloyd Barrage Canals has brought the question of communications to the forefront, as the success of the project and the prosperity of the irrigators will depend on economical transport of the increased out put from the greater area being gradually brought under irrigation. Unfortunately we are a deficit province and though being assisted by the Government of India, it will be many years indeed before we should be able to spare funds for making first class roads of modern construction. A demand for them is however bound to come when the large increase in the present traffic will make their necessity felt in the near future. At present we have to rest content with as cheap roads as possible with the soils and the local materials obtaining in Sind. The problem of road making in Sind is very difficult indeed, there being no hard materials available within easy reach, and it is rendered still more difficult by the destructive effect of the carts that are in use specially in the Upper Sind.

The carts in the Upper Sind carry 12 maunds and are provided with narrow iron tyres, 2½ inches wide with rounded edges on wheels of 2 feet 9 inches diameter and the axle is held simply between two wooden supports protruding from the frame of the cart with the result that the wheels wobble and have a snake like motion. They therefore rapidly cut up the road surface. The carts in use in the Lower Sind are of a better design and carry 15 maunds, but they too are provided with iron tyres 2½ inches wide on wheels of 4 feet 3 inches diameter.

Ignorance is not the only reason for the unsatisfactory design of the carts. These carts have to go through fields and areas cut up by old canals and water courses and they have therefore to be so constructed that they can if necessary be easily taken to pieces and taken across such obstructions where no bridges exist. The design of the Upper Sind carts readily admits of this being done. Also the design has to depend on the facilities of repairs and renewals obtainable

with the local skill of the carpenter and the blacksmiths available in the outlying villages.

Such being the case, it is a difficult problem to wipe out these old carts altogether and measures must be taken at first, I think, to make the best of a bad job.

The first step in the right direction in my opinion is to limit the weight of a laden cart and prescribe a minimum width of tyre so as to reduce the pressure on the road surface to 400 to 500 pounds per square inch and it is necessary to bring round the public opinion to the necessity of prescribing the limits by local legislation. Some advance may no doubt be made by discriminatory taxation but unless the saving due to the reduced taxation is likely to more than compensate for the costlier types of carts, the advance will not be appreciable.

In the modern projects sufficient provision is made for bridges on the irrigation channels and in the areas affected by them it should be possible to introduce better types of carts to achieve the same end. Our Agricultural Engineer Mr. Cumming has given great thought to the matter and I would bring to the notice of the Congress that he has designed a cart suitable for agricultural use and less destructive to road surface. Its capacity is 36 maunds and it is provided with iron wheels of 4 feet diameter, self lubricated, and with 5 inches wide tyres. The cost of the cart is Rs. 150/-. The comparative tests carried out at Sakrand Farm showed that with the Cumming cart there was less sinkage and reduced draught than that with the Dunlop cart. I have got a drawing of the cart and shall be glad to show it to those interested in it. If any more details are required I shall be glad to get them.

As time passes and the agriculturists become more prosperous and educated, the rubber tyres may take the place of iron tyres, but at the present stage a cheaper cart with wide iron tyres like that designed by Mr. Cumming requiring practically the same draught as that for a cart with pneumatic tyres is a better proposition from an agriculturist's point of view and is likely to be more popular. Of course the pneumatic equipment is suitable even now for carts for town use.

No doubt if the bullock cart users, the pneumatic equipment manufacturers and the Government or the local bodies responsible for maintenance of road communications could be made to cooperate each sharing the burden in proportion to the gain obtained by the use of pneumatic tyres, the use of pneumatic tyres can be extended to a certain extent, but I think it will be rather difficult to bring about such a cooperation in practice. A subsidy by Government and pneumatic tyre manufacturers to the bullock cart users may possibly result in greater use of pneumatic tyres than at present and I think the possibility of such a combination should be explored to find out if it is feasible. Mr. Cumming was taking great interest in the improvement of carts, but I am sorry to learn from papers that he passed away after a short illness about a week ago.

Mr. P. L. Bowers (Jaipur):—Chairman and gentlemen,—I congratulate Mr. Moss on his very well thought out and interesting paper on a subject which has given road engineers food for thought for many years. His Excellency yesterday while welcoming us to Lucknow warned us that we were expected to deliver the goods and like the Israelites of old to get on with our job of making bricks. At the same time he informed us that the supplies of straw in the shape of financial assistance are strictly limited and he further warned us that the number of the worst enemies to our roads, namely bullock carts, exerting a mean intensive pressure of from 500 to 900 pounds a square inch on our road surfaces,

was on the increase. This being so, it is evident that we are caught in a vicious circle, increasing loads on our roads more expensive forms of construction and limited resoures with which to cope with these increases. To my mind if we are going to make any improvement in our road surfaces we must ask Government to provide us with a different blend of straw, a well graded mixture of financial aid and legislation, to bring about a decrease in the intensity of pressure on our road surfaces.

There are two ways in which Government can assist. The first of which may seem fantastic but nevertheless possible, and one which I, having a certain small interest in rubber, would welcome, namely the diversion of the Road Fund from road improvement to the betterment of country vehicles, by assisting their owners to replace iron tyres by rubber tyres. The second which is probably more practicable is the introduction of legislature to reduce the intensity of pressure on our roads to the neighbourhood of 200 pounds per square inch by limiting the weights carried by country vehicles in proportion to their effective tyre widths. Machinery to effect this would probably have to be provided at the expense of the Road Fund, but as this is a question of all-India importance it does not appear to me that there will be any insurmountable difficulty in doing so. The benefit of reducing the pressure is clearly shown in the State from which I come. In Jaipur where practically all country tracks are sand, the farmers have found by experience that wide tyred carts are the most economical to use. Tyres upto 4 inches width are not uncommon and the average intensity of pressure between the iron tyres and the road surfaces is probably never greater than from 250 to 350 pounds per square inch. Under this pressure on tarred macadam roads, the aggregate used for which is certainly no better than that found in Delhi, it is found that the road stands up under intensive traffic from our quarries for a considerable number of years with little or no signs of rutting and with only small expenditure on surface patching. This to my mind proves conclusively that although the general introduction of rubber tyred carts may be the ideal to aim for, much improvement in road surfaces and reduction in the cost of maintenance and repair can be effected by forcing a gradual increase in tyre widths by making the use of narrowed tyred vehicles even less economical to the owners than it is at present.

Mr. G. B. Vaswani (Sind):—I am very glad that this subject has been brought before a body like the Indian Roads Congress. Many times we get literature from the Dunlop Rubber Company and the Local bodies do not take it favourably because it emanates from manufacturers, who are naturally interested in the sale of their own goods. Now it is for the Congress to decide whether iron-tyred wheels have a destructive effect on roads. On our last inspection, which was in Lucknow, we found that the road surface in three-fourth of the width of the road was all right, whereas the other one-fourth where the iron-tyred traffic had been allowed was torn up and was under repairs. We also found at Cawnpore that the cement concrete portion of the road was cut up on account of traffic of heavy brick loaded carts. The United Provinces Government have now introduced cement concrete roads, costing Rs. 22,200/- per mile of road. This amply proves that the iron-tyred traffic has a very destructive effect on road surface. This fact having been established, it is for the Congress to come to the conclusion whether it is necessary to introduce pneumatic tyres for carts. If the Government had power they could issue a *Firman* from today that no more iron-tyred traffic would be allowed on roads. But we are living in a democratic age where representation is by election by voters with Rs. 2/- franchise and where the poor man has a vote, and we cannot remove him from the road. Therefore where force cannot be applied, persuasion should be tried. It

is now our problem as to how we should persuade the drivers of carts to replace iron-tyred wheels by pneumatic tyred wheels. In cities we find that if pneumatic tyres are introduced, the Society for the Prevention of Cruelty to Animals comes in. According to the pamphlet we find that 50 to 60 maund loads can be put on a bullock-cart fitted with pneumatic tyres. If we read the scales of the Society for the Prevention of Cruelty to Animals, we find that they allow 20 maunds for carts fitted with iron-tyred wheels and 30 maunds for those fitted with pneumatic tyres. If there is only a difference of 10 maunds in the loads allowed on pneumatic tyred carts, what then is the use of introducing pneumatic tyres? Therefore, I suggest that the Council of the Roads Congress should lay down a scale of the loads for carts fitted with iron-tyred and pneumatic tyred wheels. The scale of Society for the Prevention of Cruelty to Animals is the same for rough roads and asphalted or cement concrete roads. Therefore the first step should be to allow the maximum loads for carts which are fitted with pneumatic-tyred wheels.

Secondly, the Dunlop Company must give tyres on easy payment system. If one tyre equipment costs Rs. 150/- then the cost should be divided into ten instalments of Rs. 15/-, which the driver can easily pay.

Thirdly, the municipalities should be induced to reduce the wheel tax on pneumatic-tyred carts. Some municipalities have already taken steps in this direction. Therefore if the Council of the Roads Congress write to all Municipalities asking them to reduce the wheel tax by fifty per cent (or whatever other figure they think best) on all pneumatic tyred carts in the interest of road surface on the ground that it will repay them in the long run by a corresponding saving in repairs and maintenance charges on roads.

These are the three suggestions which I make for the introduction of pneumatic tyres, which if adopted by the Roads Congress will greatly help in their adoption by cart-owners.

Mr. W. A. Radice :—Mr. President and Gentlemen,—The last speaker has made some most interesting suggestions. In view of the *proposal I have made during the business session of this Congress and the ready acceptance accorded to it by you, I would strongly support the suggestion that this Congress should undertake a research into the comparative destructiveness of various types of bullock cart wheels on various surfaces from say the sandy kutcha roads of Sind to the best modern road surfaces available.

Bullock cart wheels and tyres vary considerably for example the light bullock carts of Bombay have wide flat tyres ; in Calcutta they have narrow tyres of curved section. If there were available to road authorities accurate comparative costs of wear and tear due to these various tyres on various roads backed by the Authority of this Congress the framers of bye laws would have an easier task in minimizing damage to the roads ; perhaps by very simple means imposing no hardship on the owners of carts.

It appears that even at this stage there is a general consensus of opinion amongst members that the general adoption of the pneumatic tyre would yield considerable benefits to all concerned ; to the cart owner, to the public and to those in charge of road maintenance. Seeing that practically everybody here is an engineer in charge of road maintenance and construction it would seem that the remedy lies, to a considerable extent, in your own hands. Most of you have

*Minutes of the Business Meeting of the Third Indian Roads Congress, Lucknow, February 1937.

in your daily work to let out contracts for the carting of large quantities of road materials against sanctioned estimates. It is therefore in your power to encourage the adoption of pneumatic tyres by showing some preference to tenderers undertaking to use only carts so fitted. Such a policy might increase costs of cartage but it seems reasonable to suppose that once a contractor has equipped himself with the improved carts he will soon see where his advantage lies and the financial inducement suggested would soon decrease and most likely even disappear. I would venture to guess that if once a carting contractor adopts the better tyres and finds an advantage therein, others will not be slow to copy his methods. The temporary increase in costs of this educational process would soon be amply repaid by decreased maintenance costs.

Mr. W. L. Murrell (Bihar):—Chairman and gentlemen,—Years ago I did a fair amount of voluntary experimental work in miles 249 and 250 of the Grand Trunk Road, the series including cement grouts and sand-wiches, tar and bitumen-emulsion grouts, and sealing of water-bound surfaces with tars, bitumen, and bitumen-emulsion. The intensity of bullock cart traffic over these experimental sections was not much, but it quickly showed that the bullock cart wheel was complete master of anyone who desired to improve road surfaces. It was this experience that led me to suggest in *1930, in "Indian Engineering", a means of tackling this question. The task before the wheel improver is a stupendous one, and the following incident is cited as being possibly a typical obstacle constituted by the technical ignorance of those whose duty it is to see that public money is not wasted. The Manbhum District Board, in their special meeting on the 28th March, 1936, actually amended their Bye-law No. 28 so that the minimum width of tyre might be 1¼ inches instead of 2 inches as previously. This seems incredible, but it is a simple fact. Apparently the members of the Board were under the impression that, by making the *width* of tyre less, the weight of the cart and therefore the effort of the poor bullock would be decreased.

Another touch that will interest the engineer is the fact that the revenue of the Manbhum District Board depends chiefly on the economic condition of the Jharia coalfieds, and incidentally on sales of crude and distilled tar. The 1¼ inch steel tyre would, of course, render utterly impossible the large programme of tar sealing that all members of the Board would like to see in their own district if not throughout the rest of the Province. It should perhaps be stated that the Manbhum District Board is probably as go-ahead and up-to-date as any Board in the Province. It might be mentioned that the Deputy Commissioner did his best to point out to the Board the fundamental mistake concerned and, in the end, the Inspector of Local Works had to approach Government to prevent the amendment having the force of law.

From this it appears reasonable to form the following two conclusions:—

(a) The improver of the bullock cart wheel has an almost hopeless task.

(b) Local bodies should not have the power of making any bye-laws on such matters.

I should like now to remark on the fact that there appears to be only one size and type of pneumatic bullock cart wheel and axle, and that size is meant for fairly heavy loading. I would like to refer to page 44 of the Proceedings of

*"Indian Engineering" 1st February 1930. Review on Papers of the Bombay Engineering Congress 1929 and something about Road Policy.

by either demanding, or perhaps inducing, contractors to use only those which were fitted with such tyres for the collection of road material. Over a year ago I attempted this very thing. We called for tenders for the collection of all forms of road material for the whole of one division for a period of four years. This was not our usual custom but we extended the period and gave the option to tender for the whole division merely to increase the scope. At the same time contractors had the option of tendering for one part of the division only if they wished to do so. I had very roughly worked out—it was impossible to work it out exactly—the reasonable extra cost from our point of view, that is to say, what we would save in road repairs by the use of rubber-tyred carts, and I was prepared to pay eight annas per 100 cubic feet. We called for tenders, and I think I am right in saying that we only got three, whereas, normally for that kind of work we would perhaps get 8, 10 or even more. The amount the tenderers demanded for using rubber-tyred carts was approximately Rs. 2/- per 100 cubic feet of material carried. This included collection within the whole division and the distance might be anything from two to three miles up to perhaps ten. It was mostly for carriage of kanker from quarries or stone from the railway station. This meant that the contractors wanted us to pay not only for the whole equipment which they would still be in posse ssion of at the end of four years, but also pay them extra for the contract. We could not accept that, and we dropped it. This year one man voluntarily offered to bring in kanker on pneumatic-tyred carts at some extra rate to be arranged. It was only a small contract—I think for 2 miles—and we have actually concluded that contract with him for 8 annas per 100 cubic feet extra. My hope is that if we pursue that policy and give preference to contractors who are prepared to use pneumatic-tyred carts, others will come along in due course, and then they will start to cut each other's throat and we shall win.

Mr. N. Das Gupta:—Mr. Moss's interesting article is full of valuable information regarding relative effects of pneumatic tyred and ordinary steel tyred bullock-carts, and it cannot be denied that the latter type of cart causes the greatest injury to the roads. Mr. Moss told us that in India there were 8½ million bullock-carts. I, therefore, doubt whether we can totally eliminate from our roads the primitive bullock-carts without some legislation that every cart carrying over a certain fixed load should be fitted with pneumatic tyres. But I would say that such legislation would be clearly unfair. Asking bullock-cart owners to fit pneumatic tyres would be like asking tongawalas to run taxis. But, where is the means for this? The bullock-cart owners are mostly very poor and if they are forced by legislation to fit their carts with pneumatic tyres they would perhaps have to give up their profession. So, I say that any legislation or orders placing such restrictions would be most unfair. We should allow every man to earn his bread in his humble way. There is no doubt that ordinary bullock-carts cause damage to the roads, but we as engineers should build roads that are capable of standing up to all kinds of bullock-cart traffic instead of restricting the use of roads by bullock-cart owners. Mr. Dean spoke of two strikes by bullock-cart owners which took place in Delhi. This is inevitable when the question of earning of bread is concerned.

Before concluding I would like to tell you that I am not opposed to improvements and I should be glad to see all the bullock-carts in India fitted with pneumatic tyres, but we must not introduce any measures which will bring hardship on the poor bullock-cart owners.

Mr. R. L. Sondhi (Punjab):—Mr. Chairman, I join with the previous speaker in admiring the excellent paper written by Mr. Moss. The figure for the

destructive effect of bullock-carts on roads which he has obtained from Delhi experiments, is said to be Rs. 57/- per annum for every mile of daily travel of a cart, *i.e.*, Rs. 5,700/- per annum for 100 local carts, vide page 75. In the early part of the paper it is said that there were 8½ million carts according to 1930 Census. Of course, all of them do not ply on our metalled roads, but I think I am correct if I say that at least one per cent are using our metalled roads. If the figures for destructive effect quoted above were taken as correct then the cost of damage done by bullock-carts would amount to crores of rupees. We must admit that our metal roads in spite of the destructive effect of the iron-tyred bullock-carts on the road are not generally deteriorating to that extent. So there must be something wrong with the figures arrived at, and I hope the author will enlighten us on this point.

Mr. J. P. Anderson :—As many of the questions asked have already been answered by other speakers, I propose to deal, in detail, only with those remaining.

The gentleman from Sind, whose name I did not catch, spoke of Mr. Cummings' carts. One of them is here at Lucknow on show at the Exhibition and I have had a look at it. It possesses all the disadvantages which wide iron-wheeled carts do possess. When I saw it—which was a week or two after its arrival—the wheels, which have Iron Tyres about 3½ inches to 4 inches wide, had already flattened in several placess. It can be imagined what would be the result of using that cart for a year or two over rough roads. I have personally seen no wide iron-tyred wheel, which can be economically produced and which would stand up to really hard work. They can, of course, be made but only at great expense. A year or two ago, I had experience of a fleet of carts, in Ceylon, fitted with wide Iron-Tyred wheels, built in America, and used on a Copra Plantation. These wheels were of a very good typo but even then proved enormously expensive to maintain. They had a tyre about 4 inches wide and every year or so every wheel had to be entirely rebuilt. This fleet of carts was subsequently converted to Pneumatic Tyres entirely for reasons of economic maintenance.

Another point made in favour of the wide Iron-Tyred wheel Equipment, advocated by the Karachi speaker, was the cheaper cost as compared with Pneumatic Equipment. The cost of the Wide Iron-Tyred Equipment was stated to be Rs. 150/-. These statements of comparative costs are, however, sometimes misleading. A cart fabricated in a Government Industrial or Agricultural workshop may only cost Rs. 150/-, but, in comparing this cost with that of an article commercially produced and marketed, allowance should be made for the fact that the price of the Pneumatic Equipped Cart includes normal overhead production expenses and provision for marketing costs and distribution expenses, trade discounts, and commissions, etc., and a margin of profit. I merely mention this point although I do not know if, in the case in question, these factors have been taken into consideration.

Another delegate from Jaipur, whose name I also did not catch, advocated legislation to reduce, compulsorily, the loads at present being carried by Bullock-Carts. My own view is that anything of that nature would be regarded as causing "hardship" to the poor carter, and would likely cause riots and commotion in many places.

Mr. Vaswani asked if Pneumatic Equipment could not be made available for purchase on the instalment system. Hire Purchase Facilities are already available. He also suggested that much could be done to encourage the adoption of Pneumatic Equipment by Municipalities reducing the Wheel Tax on

carts fitted with Pneumatic Tyred Wheels. Many prominent Municipalities have already done this, including Bombay, Amritsar, Rangoon, etc., and others are following suit. The need for a revision of legislation regarding Permissible Pay Loads is a very real one. There seems to be no underlying principle for fixing Permissable loads, which vary to a great extent in different parts of India. In Bombay the maximum load permitted on an ordinary country cart is 15 maunds, while, in Calcutta, it is as much as 60 maunds. These Bye-Laws do not regulate loads in relation to the draught effort required for particular vehicles, nor, in many cases, is any account taken of the varying size of animals. As the use of rubber Tyred vehicles, with roller bearing hubs, greatly reduces the draught effort required, there is a very real need for a revision of these load regulating laws in order that vehicles of the improved type, with easier draught, may be able to carry loads in relation to the draught effort required to draw them. In this Paper it is shown that pay loads for the same draught can be increased as much as 100 per cent to 150 per cent.

The suggestion made by Mr. Radice that the Public Works Department themselves have a means in their own hands of encouraging the use of Pneumatic Bullock-Cart Equipment has already been referred to by one or two speakers, and I may add that the Public Works Department, Bombay, have recently issued a notice to all Contractors that, in future, preference will be given, other things being equal, to those Contractors who use the Improved type of Hub and Wheel Equipment. Colonel Haig mentioned that he had to pay extra for this improved transport. I do not think, however, that this will be found to be generally necessary. If tenders had been received from Bullock Cart operators who had more experience of using Pneumatic Tyred Carts, I am sure he would have obtained even cheaper rates than what he ordinarily pays. The main obstacle to be overcome is the natural conservatism and inertia of the ordinary Bullock Cart user, but once the idea has been introduced to him, he rapidly becomes enthusiastic about it. We have had ample evidence of this in the Sugar Cane areas, where there are now hundreds of ordinary Bullock Cart owners who are purchasing, on their own initiative by the Hire Purchase system, carts fitted with the Improved Wheel Equipment, entirely because they have realised the economic advantages which will accrue to them by using this type of cart. It would thus seem to be only a question of time. If Public Works Departments, Municipalities and other influential users of animal transport persistently encouraged the use of Pneumatic Equipped Carts, I feel sure that the problem will solve itself in time.

Mr. Murrell asked about the sizes of tyres available. There are altogether about 15 sizes of Pneumatic Tyres for Bullock Carts and Hand Carts, ranging from tyres suitable for loads of 5 hundred weights up to the largest type which are suitable for loads of 70 hundred weights which I think covers what is necessary for Animal Transport in this country. Prices range from Rs. 65/- per set of Wheel Equipment, comprising axles, roller bearing hubs, wheels, tyres, etc., up to Rs. 234/-, which is the most expensive and carries a load of 3½ tons per axle. Regarding the life of tyres, we have not had, as yet, very much practical knowledge of these particular tyres, but judging from the experience gained during the three years in which these Bullock Cart Tyres have been marketed in this country it seems unlikely that the tyres will ever wear out in the ordinary way. Tyres that have been in use in this country for the past three years appear to be in much the same condition to-day as they were when supplied, except that the rubber begins to show signs of ageing. Our estimate is that these tyres will begin to perish at the end of four or five years, probably nearer five years than four.

A Member:—What about punctures in tyres?

Mr. J. P. Anderson:—The incidence of punctures in these tyres is very rare, although a lot of bother is sometimes experienced in the early stages of introduction from malicious punctures caused by individuals who are hostile to the idea of this Equipment.

A Member:—What is the cost of replacing tyres?

Mr. J. P. Anderson:—The cost of replacement varies from Rs. 15/- to Rs. 60/-, according to the size of the tyre.

Mr. Sondhi asked about the figures quoted on page 75 of the Paper. These were derived from the October 1935 number of the magazine "Indian Roads".

Chairman:—I think the amount of discussion on this paper has shown that it is the most important we have had. I am not going to say much because it has already taken a lot of time. We appear to be up against a big thing if we want to introduce a better type of wheel, and I do not think that anyone will deny that it will be an improvement in equipment. But we have got to face the financial side and the opposition which may be expected due chiefly to ignorance of the cart owner. That is a matter of time. I think that Colonel Haig's experience is very encouraging. I think perhaps the best thing as far as we are concerned is that the Congress agree to leave it to the Council to inquire into this matter and by next meeting put up some form of resolution which should be the opinion of the Congress and which could be broadcast as suggestions for hastening this matter. In the meanwhile there is of course nothing to prevent the people from doing the best they can. It will take time, but it will want a lot of pushing.

I conclude by thanking Mr. Moss and his spokesman very much for the very able paper and the interesting discussion which it has evoked.

CORRESPONDENCE.

I. Further comments made by Mr. W. L. Murrell, by correspondence, on the Paper.

Mr. Anderson's reply that there are so many different sizes and types of pneumatic tyre equipment available in India quite devastated me. I would apologise for exposing my ignorance except that such exposure may have a good result.

Conversation with other members of the Congress showed that many of us were unaware of the degree of variation of pneumatic equipment available in India.

There is a fairly general opinion that vigorous propaganda is required if the rubber is to replace the steel tyre to any appreciable extent within reasonable time.

II. Further Comments made by Mr. P. L. Bowers (Jaipur) by correspondence.

With reference to the remarks I made during discussion on Mr. Moss's Paper No.36, on the subject of "Ways & means of Improving the Bullock carts", I forgot to mention that there is a third way in which Government could assist in a more rapid replacement of iron tyres by rubber tyres and that is by example.

I do not know whether rubber tyres would be practicable for use with guns, but I see no reason why Limbers G. S. Wagons and A. T. Carts should not be furnished with rubber tyres instead of iron ones as at present. I understand that

during recent operations on the Frontier A. T. Carts could not be used on account of the damage done by them to the newly constructed gravel surface roads, and that only pack and motor transport was permissible. If this is so the substitution of rubber tyres for iron tyres on all forms of Military Transport appears to be desirable.

CHAIRMAN:—Colonel G. E. Sopwith.

Chairman:—I call upon Mr. Mitchell to introduce his paper.

The following paper was then taken as read:—

Paper No. 39

OPTIMUM WEIGHT OF VEHICLES ON EXTRA MUNICIPAL ROADS.

BY

K. G. Mitchell, C.I.E., I.S.E.,
Consulting Engineer to the Government of India (Roads).

When motor transport first appeared in India it was limited to a relatively small number of private cars mainly used in towns; and did not greatly affect the roads of the country. In the last ten or twelve years, however, the number of cars, buses and lorries has greatly increased. For a time there was considerable deterioration of roads or largely increased expenditure on maintenance. The latter when it was possible was only short lived because of the general financial depression and for a time roads were a night-mare alike to those responsible for them and those that had to use them.

Then followed a certain amount of re-construction, of surface treatment with tar and bitumen as a result of which about 6,500 miles out of the total milage of the metalled roads in India has now a dust-proof and more durable surface. At the same time by unremitting care and attention to the proper renewal of waterbound macadam deterioration has been arrested on the remaining milage and some recovery of condition has been effected without any great increase in the provision for maintenance. But this improvement or arrest of deterioration has been brought about under traffic condition which as regards nature, unit loads and speeds are temporarily stable. Any great increase, for instance, in the number, unit weight or speed of buses and lorries would precipitate another crisis in that some of the improved surfaces of the lighter and cheaper type (and we must look to these for wider spread improvement) would be destroyed and the maintenance of waterbound macadam, Kankar *etc.*, would become impossible. Such a development would be a disaster to all concerned and to Motor Transport interests in particular.

The numbers of vehicles cannot be controlled to any great extent and road engineers naturally welcome increased volume of traffic which enhances the public service value of the roads for which they are responsible. The control of speeds is a difficult matter. There remains the question of unit loads and whether these can in fact be controlled in the interest of all concerned; whether in fact there is not for general conditions of India an optimum weight which will serve the needs of rural transport without unduly destroying the roads; what that weight should be; and whether vehicles can or should be restricted by law to that weight.

This question was raised as long ago as 1931 in "Indian Roads" (No. 1. July 1931). It did not then attract the attention it deserved and nothing happened. Fortunately, however, there has since then been no marked tendency for the weights of vehicles to increase and no great harm has been done by the delay. The question has now been raised again—this time by a committee of the Transport Advisory Council—and the subject of this paper is to elicit the opinion of the Congress as a body entitled to speak on behalf of Engineers responsible for roads. Any opinion expressed by the Congress will be given due weight when the matter is further considered and the writer ventures to hope, therefore, that members will give the matter due consideration not only from their own particular angle as road providers but also from their observation of the trend and needs of rural transport and their knowledge of the resources available to provide funds for roads.

It may be alleged that in this matter the Government of each Province or State can well look after its own interests. Ultimately of course these Governments will have to impose any control that may seem good to them. But in the general interest of trade and the free movement of transport it is suggested that, if conditions do not vary greatly, uniformity is desirable.

It is hoped that from the discussion of this paper, and possibly by a resolution of the Congress, it will be made clear how far conditions permit of general uniformity.

An examination of the present tendencies regarding the manufacture of motor "trucks" *i.e.*, bus and lorry chassis affords evidence of what we may expect to have to provide for on Indian roads in the near future. The biggest producers of motor trucks being the United States and Canada and a very large percentage of the trucks used in India being imported from those countries, their out-put in recent years should indicate the vehicle which is most commonly used. The following table shows by "capacity" the out-turn of motor trucks in the United States and Canada during recent years. No figures are available later than 1933.*

TABLE†

Class of trucks by capacity.	1923	1926	1929	1930	1931	1932	1933
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
3/4 ton or less ...	16.5	17.8	17.1	24.0	25.2	32.3	27.6
1 ton to $1\frac{1}{2}$ tons ...	67.7	62.4	9.5	5.2	1.1	0.6	0.2
$1\frac{1}{2}$ tons to 2 tons ...	5.6	8.4	63.4	61.7	66.6	58.8	63.7
2 tons to $2\frac{1}{2}$ tons ...	3.5	3.6	3.4	2.7	2.0	3.1	4.4
$2\frac{1}{2}$ tons to $3\frac{1}{2}$ tons ...	3.0	3.3	4.1	3.8	2.7	2.4	2.2
$3\frac{1}{2}$ tons to 5 tons ...	1.6	1.0	1.0	1.0	1.0	1.1	0.8
5 tons ...	1.1	1.6	0.3	0.2	0.2	0.6	0.2
Over 5 tons and special...	1.0	1.9	1.2	1.4	1.2	1.1	0.9

*Figures for the years 1934 and 1935 which became available before these Proceedings were printed, will be found under the head "Correspondence."

†"Facts and Figures of the Automobile Industry" 1933-34, U.S. National Chamber of Commerce.

From these figures it would be seen that the most popular trucks are those of $1\frac{1}{2}$ tons and 2 tons capacity, and that since 1923, about ninety per cent of the requirements of the United States, Canada and the countries getting their supplies from them have been met by vehicles of 2 tons capacity or under. It may be supposed that of the vehicles of over two tons "capacity" a large proportion are used within restricted areas for Industrial purposes and it may, therefore, be safely assumed that nearly 95 per cent of vehicles generally used on extra-municipal roads are of two tons capacity or less. We may consequently conclude that for general business and agricultural purposes light trucks, below two tons capacity satisfy the needs of motor transport. Hence, for the purpose of motor vehicle regulation it would cause no great hardship to prohibit the use on extra-municipal roads of all vehicles of a laden weight in excess of 5 tons. The capacity of such vehicles would be between 2 to $2\frac{1}{2}$ tons. This would mean a static axle load of nearly $3\frac{1}{2}$ tons.

The increase due to impact is very variable depending upon the roughness of the surface, the speed and tyres of the vehicle. According to impact tests made by United States Bureau of Public Roads, the increase in static wheel load due to a fall of $\frac{1}{4}$ inch at normal speeds is about 80 per cent.* This is generally taken as the probable impact on well maintained roads. Making this allowance, the peak axle load of a $2\frac{1}{2}$ ton capacity vehicle would be nearly $6\frac{1}{4}$ tons or say, 1,4000 pounds. This is probably the maximum that waterbound or surface treated macadam can be expected to carry with reasonable maintenance. This type of surface will continue for many years to be the more common type of Indian road construction. It seems, therefore, that for extra-municipal roads, vehicles having a laden weight upto 5 tons or even less will suffice and be a reasonable compromise between what the roads can carry, what the transport industry requires, and incidentally what the revenues of the country can afford for road maintenance. If use of all the roads by unrestricted heavy motor vehicles is allowed there might be a slight reduction in haulage costs but the increase in the initial cost of road construction and maintenance would be out of all proportion to this and the real cost, *i.e.*, operating charges of motor transport plus cost of roads would be greatly enhanced.

The question of speed and tyres was also discussed at some length in the first issue of "Indian Roads" (July 1931) and it is not necessary to repeat what was then proposed. These, it was suggested, should be regulated as below:—

Registered laden weight of vehicle.	Speed in miles per hour of a vehicle having	
	pneumatic tyres on all wheels.	Resilient tyre on any wheel.
(*i*) Not Exceeding 6,500 lbs. ...	35	15
(*ii*) Exceeding 6,500 lbs. but not exceeding 8,000 lbs. ...	30	15
(*iii*) Exceeding 8,000 lbs but not exceeding 10,500 lbs ...	20	10
(*iv*) Exceeding 10,500 lbs. but not exceeding 17,000 lbs. ...	15	10
(*v*) Exceeding 17,000 lbs. ...	12	10

*Vide table on page 372 of "Highway Engineers hand-book" by Harger and Bonney (4th Edn.).

Provided that in the case of a rigid frame six wheeled vehicle, the registered laden weight of which exceeds 8,000 lbs. the permissible weight shall be 15 per cent. in excess of that above specified.

In the case of every motor vehicle or trailer fitted with a resilient tyre on any wheel or wheels, the width of every resilient tyre should be such that the weight transmitted to the road by any one wheel should not exceed the following :—

	Weight transmitted to surface per inch width of tyre, *i.e*, total weight in pounds on any wheel divided by the widths of the tyre or aggregate widths of the tyres on that wheel in inches to the nearest half inch.
(*i*) If the width does not exceed 4 inches	450 pounds.
(*ii*) If the width exceeds 4 inches but does not exceed 5 inches ...	475 „
(*iii*) If the width exceeds 5 inches but does not exceed 6 inches ...	500 „
(*iv*) If the width exceeds 6 inches but does not exceed 7 inches ...	520 „
(*v*) If the width exceeds 7 inches but does not exceed 8 inches ...	540 „
(*vi*) If the width exceeds 8 inches ...	560 „

The opinion of the Congress is desired on the question of a general limitation of the gross weight of vehicles which should be allowed on extra-municipal roads in general. Its opinion on the other points will be of great value.

DISCUSSIONS ON PAPER No. 39.

Mr. K. G. Mitchell (Author):—I only want to say that this Paper has been sketchily and hastily put together in order to elicit opinion. I expect in a body of scientifically minded people to be criticised for dealing with this subject in such an imperfect manner. I would like however to suggest to you the way in which this question has arisen and placed against its proper background. The land transport system of India has during the last hundred years been greatly improved. Formerly there were no railways, the population was possibly about 60 per cent of what it is now and people were not accustomed to travel. The villages were self-contained and relied on subsistence farming. They exported nothing and imported practically nothing. During these hundred years the population has increased, people have got into the habit of travelling and railways have created an incentive to grow money-crops in the place of subsistence farming. A very recent instance of this is sugar refining which has been referred to this afternoon. The cane which was

formerly crushed in villages —and it is grown now in very much larger quantity—is now brought to mills at some distance from the villages and is carried mostly on roads. Only a small part can be transported to mills by rail. There has been progress in the construction of metalled roads during the last 90 years. During the last ten years the need for improving these roads to meet the sudden increase of motor traffic has been greatly felt. The total milage of such roads was already inadequate to meet the needs of the country when motor transport came along and definitely put a stop to the extension of milage of metalled roads by increasing the maintenance cost of those in existence and using available money for that and for necessary reconstruction of the pre-existing milage. We now apply much of our time to discussing how to save the existing milage from destruction caused by this increase of and new traffic. To use a war term we are trying to "consolidate" our position. In some provinces the thing has almost come under control, but in others it has not. More money has got to be found for reconstruction and maintenance. This is all with motor transport of a certain unit weight. The point is that if for any reason the user of mechanical transport makes up his mind to use lorries of greater capacity the damage to roads will be still greater and the tax-payer will have to bear the burden of maintaining and again reconstructing them at great cost, the vicious circle will continue and the extension of road system to which we look forward will be indefinitely postponed. It seems, therefore, from the point of view of India as a whole that it would be a good thing if the existing road system could be maintained at the present level of cost and gradually improved so that we may at the same time be able to extend it to serve larger areas. I do not suggest any arbitrary limit of weight but I do say that it would be no great hardship to keep things as they are and possibly the Congress could adopt some resolution stating its opinion, if it is of the view, that in the interest of other road users and tax-payers and of people who would like to have roads to use, there should be some limit imposed for the present on the use of the roads by heavy motor vehicles for the benefit of a small number of people.

Mr. W. A. Radice :—Mr. Chairman and Gentlemen,—I consider that Mr. Mitchell has given us a very excellent Paper and I feel that the limitation of loads permitted on the roads is a vital one of very far reaching import.

Mr. Mitchell suggests the total laden weight of vehicles should be limited. I think some of the opposition which such a proposal is bound to arise might be mitigated if instead of limiting weights of vehicles, the axle loads, or better still, the wheel loads be the loadings to which limitations might be imposed.

I would like to refer to another point. This Congress has adopted the Standard Specification presented to it at this Session by the Road Bridge Standard Committee it appointed last year to deal with the question. This specification lays down axle loads considerably higher than the proposed restrictions under discussion. Whatever may be the decision regarding the proposed limitation of axle or wheel loads considered necessary to save our roads. I earnestly beg of you not to apply these principles to bridge loadings. A bridge has a life of at least 60 years and once it has been constructed it cannot be improved or strengthened to meet changing conditions as readily as a road surface can.

In a country where industrial expansion is likely, even in rural areas, the roads will have occasionally to carry special loads in the shape of machinery, boilers, heavy castings etc. These, if carefully handled at slow speeds in special vehicles once in a way will not hurt road surfaces, but if the bridges cannot pass such loads the development of industrial plants might be seriously interferred with. An excellent example of what I have in mind is the familiar mechanical road roller.

Mr. W. L. Murrell (Bihar) :— Mr. Chairman and Gentlemen,—On the question of laden weight my comments will be very brief. Mr. Mitchell proposes a maximum laden weight of the vehicle of 5 tons, but might I suggest that the axle and not the vehicle should be taken as the unit? If axle load be the criterion, I would like to suggest that the optimum load should take account of pneumatic tyred six-wheeler commercial and military lorries of 8 tons laden weight. But it is on the question of speed that I ask you to fix your attention. Mr. Mitchell points out that we are on the brink of a crisis which may be precipitated by a general increase of speed, weight, or quantity and he appears to leave the question of speed by stating that the control of speed is a difficult matter. Might I point out that, with thousands of low-priced six and eight cylinder motor vehicles pouring into this country for the last three years, the general increase of speed is already on us. In the *journal "Indian Engineering" I once described an experiment on governing about 50 lorries plying for hire over a period of two years in 1928 and 1929, and I would state now and with confidence that, with improved speed governors and a strong body like the Indian Roads Congress to suggest the necessary legislation and institution of road patrols, the problem should not now be so very difficult. It never was impossible. During the past two or three years a new factor has redoubled the importance of the consideration of speed on water-bound macadam and gravel roads. This factor is the greatly increased width of the pneumatic tyre. The sucking action of a pneumatic tyre is a direct measure of the degree of vacuum at the point where rotating tyre is leaving the road surface after contact, and this degree is more or less directly proportional to tyre width, curvature (in the sense 1/R) and the square of the speed. It is this sucking action that weakens water-bound macadam and gravel by causing the movement of water or blinder particles within it. And worse still, the weakening occurs just at the time when the point concerned is subject to the heavy horizontal driving thrust from the vehicle, which thrust is the cause of road corrugation. I submit that, with increased and increasing tyre width and speed, the factor Width into Square of speed is as threatening to water-bound macadam as the indigenous bullock cart wheel is to any higher form of road surface. Or, so long as bullock cart wheels make it uneconomical to have higher types of surface than water-bound macadam or gravel, speed over such surfaces should be controlled. Doubtless the use of twin tyres in lieu of single super-baloons would be an improvement. Before closing my remarks I would like to cite an incident concerning loading which occurred recently in Bihar. Seeing that the Hazaribagh District Board were to discuss a proposal on November 21, 1936 for a bye-law to permit of a fine of Rs. 10 for exceeding the advertised safe load on any bridge or culvert, I suggested to the Board that the fine limit be raised to Rs. 100 and the offender be liable also to pay for all damage done. The Board decided on the Rs. 100 limit but had to reduce it as the Local Self Government Act provided Rs. 50 as the maximum penalty for infringing a bye-law made by a district board. It seems obvious that such legislation should be centralized.

Mr. D. E. Gough:—Mr. Chairman and Gentlemen,—The first and main question raised by Mr. Mitchell's Paper is this: Is a uniform maximum laden weight for motor vehicles on rural roads throughout India desirable?

I submit that the key to the reply to be given by this Congress is contained in the second paragraph on page 93 of Mr. Mitchell's Paper, where it is

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* "Indian Engineering" for 2nd, 9th, and 16th August 1930.

" Notes on the Roads of Cousin India and on Engineers, Policemen, Deputy Commissioners, and Governors."

suggested that uniformity is only desirable *if conditions do not vary greatly.*

Those of you who have travelled throughout India will be the first to admit that probably in no other country in the world do the types of country met with, the road making materials employed, and the conditions of extra municipal roads already in existence, vary so greatly as they do in India. This being so, it naturally follows that a uniform maximum for the whole of India is not desirable.

Neither would it be economically advantageous. There is a vast milage of roadway in existence in India which has been built for and is fully capable of carrying greater maximum loads than 5 tons. Is the money which has been spent in preparing these roads, building the bridges etc., to be wasted by prohibiting larger and probably more economical transport from running on them? Consider for a moment a similar proposal in connexion with a railway system. Would any traffic manager dream of prohibiting the use of his heaviest locomotives over the main lines of the system, because the minor or branch lines were incapable of carrying any but light locomotives?

The adoption of a uniform maximum weight will remove vehicles above that weight from roads which are capable of carrying them, but will not of itself provide any more roads to carry vehicles up to that maximum weight, nor will it raise the standard of all existing rural roads up to that maximum. It is for these reasons that I heartily support the Indian Roads and Transport Development Association's counter proposal that, instead of fixing a maximum weight for vehicles, the Central Government should recommend all Local Governments to construct or improve rural roads to be capable of carrying a uniform *minimum* weight. The Central Government could insist upon this in the case of projects financed from the Road Fund.

Mr. Mitchell produces statistics and other evidence to justify his conclusion that the "30 hundredweight" class of vehicle satisfies the needs of rural motor transport in this country and that regulations prohibiting the use of larger vehicles would therefore involve no hardship. If this is really the case, where is the necessity for imposing such regulations? For the operator knows as well as anyone what his needs are and will surely purchase accordingly. Actually I am afraid that the Government are aware that in the normal course of events there will be a tendency, common to other countries, towards the operation of heavier vehicles as being the type which is the most economical and which the country's agriculture and commerce require. One has only to look back over the last half century to see that the trend has been for larger and heavier vehicles to be employed in all forms of mechanical transport, *e.g.*, ships, railways, tramways, aircraft. I suggest it is economically unsound to check this natural progress, provided road maintenance costs can be kept down by other means.

Please do not think for a moment that I am proposing that a vehicle should be allowed to run in excess of a road's capabilities. The more important factors causing damage to rural roads are bullock cart traffic, climatic conditions, weight and speed of motor vehicles. There is no need for me to enlarge upon the appalling damage done to rural roads by bullock cart traffic. Yet there is no suggestion to limit the weight of these vehicles. As to motor traffic, I do not believe that any road engineer would care to say that the weight of a properly loaded heavy motor vehicle, moving at a reasonable speed, fitted with suitable pneumatic tyres, provided also that it does not exceed what the bridges and culverts will carry, does any appreciable damage. On the contrary in regular

service it may even improve a road surface. Speed is by far the more important factor in connexion with road damage. For example I would even suggest that a pneumatic-tyred truck weighing four tons, travelling at 50 miles an hour, is likely to be doing more harm to a water-bound macadam road than one weighing 8 tons and travelling at 25 miles an hour. Yet the proposal is to prohibit trucks above two ton carrying capacity which form a negligible percentage of present day motor transport, while allowing the 30 hundred weight and two-ton trucks and buses which probably form 90 per cent of those on the roads to run at uncontrolled speeds and so cause very serious damage to roads. I submit that Government would be doing a greater service to roads by controlling speeds of all commercial vehicles to reasonable limits, rather than prohibiting some from the roads altogether.

Mr. Mitchell's Paper has been written on the assumption that speeds are difficult to control. Has the Government of India or any Provincial Government carried out tests of the speed governors at present on the market and in general use in most civilized countries ? If not, I suggest that would be a very good thing to do, because it would show them that speeds can be satisfactorily controlled with advantages not only in saving of road maintenance costs but also to the truck owners in longer vehicle-life and improved petrol consumption. Many British manufacturers of motor trucks fit speed governors as standard equipment, and I am sure they would not do this if they felt that the governors were not efficient. The governors are so designed that they can be sealed and it is not possible to tamper with the setting without breaking the seal. If brought into general use in India, tampering with settings would, I am sure, become infrequent provided that the first few cases discovered were severely dealt with.

While opposing the proposal for an all-India weight restriction, I agree, of course, that local authorities must lay down weight limits according to circumstances. It is here that this Congress can serve a useful purpose by suggesting the basis upon which regulations on the subject should be laid down. To begin with, in fixing weight limits for the purpose of saving damage to road surface, it is unscientific to base the regulations on gross vehicle laden weight alone. The limits in the case of pneumatic tyred vehicles should be according to axle load or better still to wheel load. Dual rear wheels namely, 4 wheels per axle, should be allowed to transmit a greater axle load than single rear wheels, and no wheel loading should be allowed to exceed the loading guaranteed by the tyre manufacturers. A fault that I find with the paper is that it takes no account of the important development in the use of low pressure tyre for distributing the load and so reducing road damage. I suggest that this might be taken into consideration when fixing allowable axle or wheel loads. The last part of Mr. Mitchell's Paper deals with the conditions for the use of resilient tyred vehicles. I am sure we must all be agreed that the less these are used on rural roads the better, and therefore we should welcome any reasonable regulations which would discourage this rapidly disappearing type from using our extra municipal roads. Lastly I would suggest that there should be a classification of roads throughout India to definite standards and we should have road maps prepared on the lines of those published for Ceylon, so that transport owners can tell at a glance what weight of transport can be operated over various roads.

Mr. V. S. Srinivasa Raghava Achariyar (Madras): We have some troubles about the increase of the weight of lorries. The popular buses in South India are twenty-seaters and they weigh about four tons gross load, while the popular lorries vary from five tons to eight tons, except the Diesel lorries which weigh four tons. As there is no control over their speeds or routes, or the margin of excess over their pay loads as recognized by the makers, the lorries

damage the roads more than the buses. From the requirement of South India, I would recommend for the consideration of the Congress that the maximum weight of lorries should be limited to four tons; that these lorries should have dual wheels on the rear axle; that their speeds should be limited to 15 miles per hour that they should be restricted to trunk and marketing roads and other metalled roads in each district, that there should be no difference between private lorries and those for hire in their taxation—and that heavier vehicles over five tons gross weight should be localized in municipal and industrial areas. I have got a list made out of the names of transport motor vehicles which are popular in South India. These are Ford, Chevrolet, Reo, Bedford and Mercades Diesel lorries which are able to carry three tons of pay load.

Lt. Col. W. de H. Haig (United Provinces):—Mr. Mitchell's suggestion, I think, is that in order to avoid possible rapid deterioration of roads owing to a great increase in the number of heavy motor vehicles, restriction in some form or other should be applied: but there is one aspect of this question which has not been touched on.

If this Congress makes a recommendation to the Government of India that restriction in some form should be applied to motor vehicles, and if we do not make any recommendation in regard to bullock carts, it seems to me that people will think—"Here is a body which is supposed to know all about roads and the destructive effect of vehicles and they have recommended restrictions on motor vehicles but have made no mention of bullock carts. Evidently they think that bullock carts do no damage". Therefore, if we consider it necessary to make recommendations regarding bullock carts we should also include bullock carts.

In connection with a previous paper (Paper No. 36) several speakers pointed out the difficulties in the way of introducing legislation imposing restrictions on bullock carts but I do not consider that that means we should refrain from making any recommendation merely because there are difficulties in giving effect to them. Our recommendations in respect of motors may be accepted and those regarding bullock carts refused but the absence of any such recommendation might be read as meaning that the Congress does not think that restrictions are necessary in their case.

Mr. Arifuddin (Hyderabad):—Mr. Chairman and Gentlemen,—With regard to Mr. Mitchell's paper I want to say that in Hyderabad we have already got legislation limiting load and speed on mooram and metal roads. I was a member of the Committee appointed to consider the question. I do not remember the limits we fixed, but I shall send a copy of the rules to the Secretary of this Congress for consideration by the Council of this Congress. For mooram and earth road we do not allow a bus or lorry weighing more than three and a half tons, as we found that heavy lorries play havoc with mooram in scooping out the soil by suction action and also by removing the soil by friction. On metal road although the pressure of even heavy lorries per square inch of the tyre in contact with road is not excessive, but the impact on the road is a factor which cannot be ignored. We know how waves are formed by even light traffic. When heavy weight lorries are used, and particularly of uniform wheel base, the effect on the metal road should be much more than that of light buses. For these reasons it is highly advisable to determine and limit speed and load on metal and mooram roads. It is highly essential that the speed must also be limited. Mr. Mitchell proposes 35 miles as the permissible limit of speed, for lorries between 6500 and 8000 pounds. In my opinion this should not be more

than 30 miles. Even light lorries weighing between 2 to 3 tons should have a speed limit. I found in Hyderabad that mooram or sand used as blindage is blown away much sooner when the width of the tyre is greater and also when the speed is higher. The former requires greater maintenance expenditure. If blinding is not properly looked after, the suction action dislodges the pieces of metal and spoils the road.

Major W. B. Whishaw (M.E.S.) :— In this paper statistics are quoted from a book by Harger and Bonney. I therefore take the opportunity of reading one paragraph from the same book which is of some interest in this connexion.

"Occasional extremely heavy loads far above the normal vehicle load are not disastrous to the macadam type, as this type of road is more or less self-healing and knits together again under rolling or well-distributed normal load traffic; that is, *macadam roads can be safely designed for the normal maximum vehicle load.*"

This paper shows that there has been no very great tendency in America for the heavy vehicle to develop in any quantity, and I think that in India this tendency would probably be less; since India is a less highly developed country and the benefits to be derived from large motor vehicles are very much less.

I therefore suggest that our present roads will be able to carry the small number of heavy motor vehicles that are likely to come on to them.

Mr. R. L. Sondhi (Punjab):—Mr. President and Gentlemen,—I congratulate Mr. Mitchell on his very excellent Paper. The author has not enlightened us on the point as to whether any laws restricting the bus or lorry limits heavier than six tons on the lines fore-shadowed by him for application to this country, exist in America and Europe. It appears that no such restrictions exist there, and if the economic needs of those places could automatically bring about a balanced state of affairs there should be no cause for anxiety in the case of India. The table at page 93 of the paper shows that the manufacture of trucks of five tons and over capacity is hardly 1 per cent of the total manufacture, and the plying of such units on the roads in those countries would be an exception rather than the rule. The industrial development of those countries is much ahead of ours, and if without applying any restrictive laws the heavier type of trucks do not make extensive appearance there we need not consider the problem, at least at this stage. If the economic trend in transportation automatically boils down to the extensive use of two-ton trucks, one would not see the advisability of recommending restrictive traffic laws. Why irritate the road users out of whom ultimately funds for the maintenance, construction and development of roads are obtained? While suggesting that this Congress should not agree to the limiting of maximum capacity for trucks, it should agree to the excellent suggestion of Mr. Mitchell that the widths of tyres should be such that the weight transmitted to the road by one wheel should not exceed certain reasonable limits; and further that the speed of vehicles should be regulated. I would, therefore, suggest that instead of asking us to lay down a maximum weight for a vehicle, which after all is a matter for the user and not the engineer who has to administer to the needs of the former, rather than regulate his movements, it will facilitate our designing of roads if instead of unit maximum, loads per square foot of the road surface are specified.

Mr. N. Das Gupta :—Mr. Chairman and Gentlemen,—I would like to know from Mr. Mitchell whether trunk roads fall under the category of extra municipal roads. If so, I think the limit of two-ton lorries is rather on the low side. I do

not encourage road-rail competition, but I like to say that the railways are not always the best means of transport and so the roads are gaining popularity for transporting goods over a reasonable distance. We can load our consignments right from one godown and deliver it at the other godown directly. But if we were to send the goods by train, we had to carry it to the nearest railway station and book it there. It would take several days for the goods train to come and deliver the goods at the other end. Then, again, cartage on the goods will have to be paid. So, there is delay and higher cost in railway transport over relatively small distances. In such cases the goods can be delivered much quicker by roads. For these reasons the road transport is gaining ever-increasing popularity. If we now put a limit to the vehicles as two tons, this form of transport will be no longer economical. Unfortunately, in Mr. Mitchell's paper we do not get any figures for the outturn of motor trucks in the United States and Canada after 1933,* as these figures were not available. I believe during the past three years more changes have taken place than that between 1923 to 1933, and we would not wonder if we find the amount of 2—2½ tons or 2½—3½ tons as 63.7 per cent in 1936. I do not think that time has yet come when we should be eager to put a limit on motor trucks and lorries. For the present we can only watch the development of road transport and its effects on our roads. This useful form of transport should not be nipped in the bud.

Mr. E. A. Nadirshah (Bombay):—Mr. Gough appears to be against any restriction to be put on the weight of vehicles. I would like to know what he proposes to do to remove existing restriction in certain provinces where restrictions already exist in some places. For instance, in Bombay Presidency there are such restrictions and heavy lorries are not allowed over certain Roads. If such restrictions do exist in certain provinces would it not be advisable to have a general uniform weight restriction in all the provinces of India? I may be permitted to make it clear that nobody would favour restrictions in weight carried by vehicles as by doing so the growth of a particular industry is curtailed but if we are compelled to choose between "No Restriction in weight and Bad Roads" and "fairly good Roads with certain restrictions", I would accept the latter proposition. I agree with a former speaker (Col: Haig) who said that when we impose restriction on motor vehicles we should also do that in the case of bullock carts etc. This is a sound argument, but a majority of bullock carts are used by agriculturists who are very poor people and form 80 per cent of India's population. These people cannot afford to equip their carts with pneumatic tyres. I suggest therefore that instead of restricting weight carried by Bullock carts a legislation may be introduced for abolishing all taxes on bullock carts fitted with pneumatic tyres. Such a legislation would induce the agriculturists to equip their carts with pneumatic out-fit and at the same time the destructive effect of iron tyred wheels on road surface will be greatly reduced and the desired effect will be produced without any opposition.

Mr. K. G. Mitchell (Author):—I will endeavour to reply to the points raised by various speakers as far as possible, but if I fail to do so in any case I shall be glad to answer any queries afterwards. I quite agree with Mr. Radice that eventually if any form of restriction is introduced it might well be on the basis of axle load or on the basis of load on the tyre. I merely put a preliminary proposal in a general way in accordance with present conditions of exclusively four wheeled vehicles of more or less uniform type. I quite agree with him that the design of a bridge has a life of 60 years and we should not design bridges in accordance with any temporary restricted loads.

*Figures for the years 1934 and 1935 which became available before the Proceedings were printed, will be found under the head "Correspondence".

As regards speed various people have had a good deal to say about that. It is satisfactory to find agreement that speed is a most important factor and that a serious attempt to control it must be made. Mr. Murrell and various other speakers have referred to speed and speed governors. We have been discussing the use of governors in the Transport Advisory Council, and there have been many difficulties and objections raised. We have asked the Indian Stores Department to get hold of a number of speed governors available on the market, and to let us know whether there is a satisfactory governor for Indian conditions. I do not propose to say more about that until we receive their report. If satisfactory governors can be found they will be used. A representative from Bihar (not Mr. Murrell) once told us that speed governors should be discouraged because they are dangerous, his expression being that a driver driving a vehicle fitted with a speed governor never takes off his foot from the accelerator and always drives at say 35 miles per hour because that is allowed by the governor and must therefore be legal. That and other objections to the introduction of speed governors have been raised more than once.

Mr. Gough started by saying that uniformity is not desirable. I should have thought that from every point of view uniformity is desirable unless motor vehicles are to be unduly localised. Mr. Gough said that there are thousands of miles of roads in India which have been improved at great expense and should be capable of carrying very much heavier loads than the loads mentioned in my Paper, and that if they are not then we—I mean the people who have been responsible far spending that money—have wasted it in a scandalous manner. What is the actual position? Assuming that there are 75,000 miles of extra municipal roads, I suggest that only eight per cent of the total has been so improved and made capable of carrying much heavier loads than the rest. That eight per cent is not distributed in one uniform length. It is scattered about in isolated lengths here and there where the intensity of total traffic—there are after all other road users than motor transport—has made improvement necessary. We do not want to have unnecessary restrictions, but in the present state of development of transport in India, I cannot think that there is any road which has a uniformly high efficient surface for a very great distance. I wish some one from the Punjab or N. W. F. P. had spoken because it is only there that there are continuous lengths of improved road. The road from Delhi to Khyber Pass is all I believe tar but even there some limit of load is presumably necessary. Elsewhere adjustment of load permitted to the nature of road surface is not a practical proposition. Mr. Gough also said that heavier motor vehicles if run at slow speed do little or no damage. I have no quarrel with that, but there is difficulty of restricting speed, and I have said in my Paper that occasional heavier loads would be allowed subject to speed restriction. There is however a possibility that a sudden increase of vehicles very much greater in weight than we have at present, handled by the same class of people who use vehicles now would do damage because they would not maintain any speed governors or would put the governors out of action.

There was a question put to me: "Why have the Government of India not adopted the practice of other civilised or semi-civilised countries and investigated speed governors"? I have already replied to them. But would like to add that India imports her motor vehicles from civilised countries and they generally come with the standard equipment required in those countries. Where are the governors which it is suggested those countries require as standard?

Mr. Raghava Achariyar wants the load to be restricted to 4-tons and speed to 16 miles an hour. That is going very much further than I had contemplated.

Col. Haig's remark that the Congress should advocate control of loads and tyres of bullock carts, and not merely refer to the loading of motor vehicles is very important. I agree that people might draw a wrong inference if both these kinds of vehicles are not mentioned together in any recommendation the Congress may make. I said at the beginning that if the Congress wished to record its opinion on this paper it might perhaps do so in the form of a resolution. We have referred the previous paper on bullock-carts—*e.g.*, whether there is prospect of anything being possible to restrict iron tyred bullock-carts—to the Council with the suggestion that it should put up a resolution for consideration next year. And the same might be done in this case.

I have been unable to turn up the quotation from Harger and Bonney which Major Whishaw made but a possible explanation is that the authors refer to bituminous and Tar macadam as being more usual in America than water bound. I do not think that any one could say that water bound macadam under Indian conditions is "self-healing" or knits together again under normal traffic.

Mr. Sondhi asked whether there are any laws in England and United States regarding load. No laws there may be in England would apply here because the roads are totally different I do not think that there is much point in saying that we propose to restrict in a manner which is not done by other countries. But it should be a matter of reason to restrict the growth of heavy transport to loads which you cannot carry without reconstructing roads you have already with difficulty improved. There is already legislation about speed and load restrictions in Hyderabad we are told.

Mr. Nadir Shah emphasized the desirability of reasonable uniformity. I agree with him.

There was one speaker who expressed his preference for road transport over railways. That question does not arise here. The object of my Paper is only to suggest that in order to save existing rural roads from destruction by the ever-increasing traffic of heavy motor lorries, some restriction should be imposed so long as we are unable to extend the road system where it is so greatly needed.

One member objected to imposing any restriction on carts because most of them are agricultural carts. Our Delhi Census showed that if you could eliminate steel tyred carts which are used by professional cartmen not for their agricultural purposes but as a business you would do away with something like 75 per cent of the steel tyred carts which do greatest damage to the roads. Agricultural carts proper often have no iron tyres.

I would like to say that if the Congress agrees, the subject matter of my Paper could be considered by the Council and reported on next year.

Chairman:—Gentlemen, I congratulate Mr. Mitchell on his interesting Paper which has produced extremely interesting discussion. Mr. Mitchell has dealt with almost all the points raised by speakers. There was one speaker, Mr. Dass Gupta, who mentioned a point which he could not answer and which seems to me to have considerable bearing on the subject Mr. Dass Gupta said that the table on page 93 only gave figures up to 1933 and he thought that since then the proportion of heavier vehicles in the United States of America had doubled. It would be a good thing if we could get figures for the years subsequent to 1933.

On behalf of the Congress I offer hearty thanks to the author of the Paper.

CORRESPONDENCE.

The following further comments have been made by Mr. W. L. Murrell by correspondence.

It is a great pity that the mechanical governing of lorries has been "crabbed" by a previous delegate, especially as he had no practical hand in the experiment.

It is interesting to learn that the Technical Sub-Committee of Congress will examine a number of contrivances for the control of speed.

If it will help the Sub-Committee, I would like to stress the point that what may prove the best speed governor for one set of conditions will not be the best for another set.

Happily, there are broadly speaking only two sets of conditions.

The first is where the vehicle has to run through sandy unbridged crossings or on steep winding roads where visibility is poor and high torque is essential at low speeds.

Under such conditions governing must only be attempted by adopting a mechanism depending on the speed of the back wheels.

The other set of conditions is much easier, and is the more frequently met with. Fairly good roads with not very long or steep inclines and no unbridged crossings need only the much simpler type of governor which fits on to the gas induction system and is mechanically entirely independent of the back axle or driving shaft.

I would like to point out that it will not be of much use laying down legal load maxima if there are no motor patrols with portable weighing machines to check up on the roadside.

Granted such patrols, it is suggested that they would be better employed in checking up speeds, examining governor seals, and keeping a watch for stolen cars, cars and lorries plying illegally, and so on.

Editorial note:—The table printed on page 93 of Mr. Mitchell's Paper gives the figures for truck production in the United States and Canada upto the year 1933. The following figures for the years 1934 and 1935 have since been communicated by Lt. Colonel H.C. Smith as desired by Colonel G. E. Sopwith during the course of discussion on the Paper.

Truck production by capacities—per cent. United States and Canada.

Class of Truck	1934	1935
¾ ton or less	28.6	34.1
1 ton and less than 1½ tons	0.4	0.3
1½ ton and less than 2 tons	62.9	57.5
2 ton and less than 2½ tons	4.3	4.0
2½ ton and less than 3½ tons	1.9	1.4
3½ ton and less than 5 tons	0.8	0.5
5 ton	0.2	
Over 5 ton and special types	0.9	2.2

Third day—Wednesday, February 24, 1937.

CHAIRMAN :—Mr. S. Bashiram.

Chairman:—I call upon Mr. Datta to introduce his Paper on "Economy and Developments of Bonded Brick Concrete roads, plain and reinforced."

The following Paper was then taken as read.

Paper No. 35.

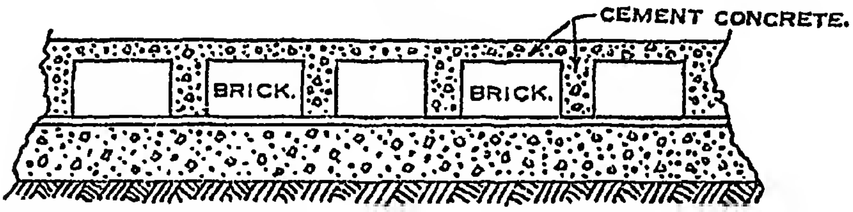
ECONOMY AND DEVELOPMENTS OF BONDED BRICK CONCRETE ROADS, PLAIN AND REINFORCED,

BY
A. K. Datta, B.E., C.E., M.I.E. (Ind), M.A.E.,
Consulting Engineer and Master Builder.

The latest economical development in the domain of cement concrete road is the "Bonded Brick Concrete Road, plain and reinforced.

1. *Bonded Brick Concrete Roads (B. B. C.)*—Bonded brick concrete with the cement concrete surfacing produces sound and economical concrete road where the subgrade is of bricks down below, with which the surface concrete is inter-bonded, by extending ribs of concrete into the joints, between the bricks. A thin concrete facing, say 1½ to 2 inches thick, when laid on ordinary waterbound macadam road, usually cracks and breaks up under heavy traffic but when the same thin layer of concrete is interbonded with a layer of bricks, it stands the traffic quite satisfactorily. Bricks, concrete at the joints and the top concrete, all work together as one mass. The upper concrete surfacing is never separated from the lower brickwork as the concrete keys prevent separation between the two. Figure 1, is an illustration.

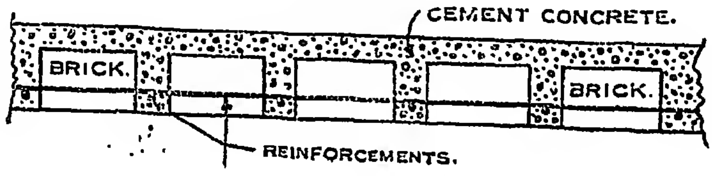
Figure 1.



This is called Bonded Brick Concrete Road as bricks and concrete are interbonded together.

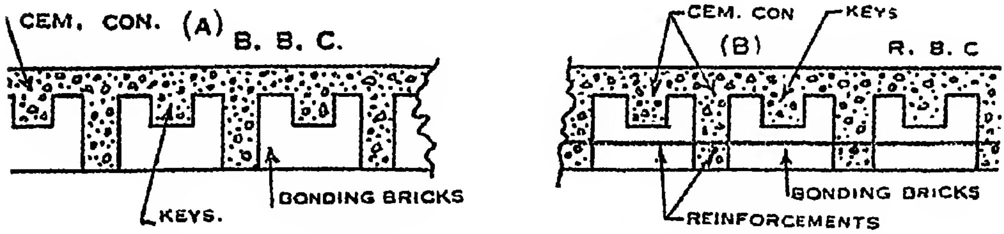
2. *Reinforced Brick Concrete (R. B. C)*—This bonded brick concrete can be used either plain without reinforcement or with reinforcement. The reinforcement is used sometimes at the bottom only, sometimes at top and in some cases both at bottom and at top. The latest American practice is to use reinforcement at top only (in cases of concrete roads) at about 2" below the top surface. Figure 2 is an illustration of an R. B. C. road.

Figure 2.



3. *B.B.C. & R.B.C. with bonding bricks with cavities.*—Further investigation has shown that the bonding between the upper concrete and lower brickwork is increased by the use of special bonding bricks with cavities, such as, 10" × 5" × 4" with two cavities 2" × 2" × 2". Figure 3 is an illustration.

Figure 3.



These have been tried in actual construction with satisfaction and success. They are as efficient as all-concrete roads.

Cement concrete as a road material has stood the test of time and heavy traffic. Of all road materials it is supposed to be the best. It provides in one, a strong foundation with a hard wearing surface. A properly constructed concrete road surface will outwear anything else known. Concrete roads are making headway in all countries of the world now for these reasons. The U.S.A. has already laid 100,000 miles of concrete roads. Canada, Britain and other countries are also making a headway in such roads. In India also good concrete roads have been constructed at Benares, Calcutta, Moghul Serai, Unao, Allahabad, Lucknow, Hyderabad, Cawnpore, Bombay, Madras and in many other places.

Good concrete roads last very long and require very little maintenance cost; the surface is smooth and not slippery and is ideal for a rapid drive.

The initial heavy outlay in cost in concrete road construction is retarding its growth in India. The total milage of concrete roads in India is only about 100 miles though we have got more than 50,000 miles of pucca roads and more than 100,000 miles of kutcha roads. The rate of progress of concrete roads in U.S.A. is about 10,000 miles a year, for the last few years whereas in India the total milage in all those years is about 100 miles only. In India the price of cement is very high as compared to U.S.A. and Britain. The price in India is about Rs. 50/- per ton, whereas in U.S.A. and Britain it is Rs. 25/- per ton *i.e.*, only half and in concrete roads the main cost is in cement. In a 6" cement concrete road (1 : 2 : 4 proportion) of 20 ft. width the amount of cement required per mile is 20 × 5280 @ 9 bags per 100 sft. = 9504 bags. Taking the cost of cement @ Rs. 50/- per ton, the cost of 9504 bags = Rs. 23,760/-. The cost of concrete road will be per mile between Rs. 50,000/- to Rs. 60,000/-. A water-bound macadam road can be laid within Rs. 20,000/- only in Muffussil towns. The excessive initial cost is the main reason why cement concrete road is not making a headway in India. The Concrete Association of India (or the Cement Marketing Co., of India) who possess a monopoly for the sale of Indian cements in India fix up the price of Indian cements. Foreign cements under heavy tariff duty cannot sell in India at a cheap rate. Combined with these facts the railway freights in India are abnormally high and increase greatly the costs of cements. If the Cement Marketing Co., reduce the price of cement and the Railways reduce the freight for cements used in road construction, the cost of cement can easily be reduced considerably say to Rs. 25/- or so per ton and concrete road can make a headway in India. The cost of Japanese

cements excluding tariff duty comes below Rs. 25/- per ton.

In order to have a wide application of concrete roads in India it is imperative to reduce initial cost without impairing the strength, efficiency and wearing capacities of the same.

Attempts have been made to use a thin layer of cement concrete say $1\frac{1}{2}''$ to $2''$ thick on a waterbound road metal surface by bonding the same with the subgrade by making a few cavities in the subgrade at regular intervals. This arrangement is a make-shift one as the main feature of the transverse strength of the concrete road surface is not possessed by the thin concrete surfacing. It is suitable as a wearing surface only like asphalt etc. on a hard road bed. If there be any settlement in the road bed due to heavy traffic the surfacing will break up. That has happened in some of the trials with thin surfacing of the concrete at Muzaffarpur, Bombay, Calcutta, etc. Thus the necessity comes in to keep the full depth of the concrete road with the concrete wearing surface.

In Bonded Brick Concrete road, plain and reinforced the full depth is retained. For example a $4\frac{1}{2}''$ concrete road will be replaced by $4\frac{1}{2}''$ B. B. C. road.

Figure 4.

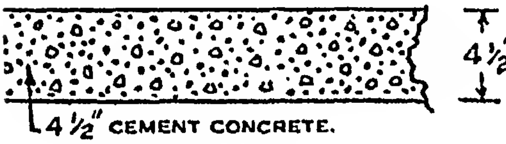


Figure 5.

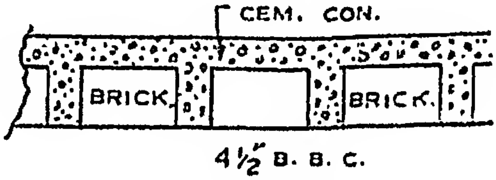


Figure 6.

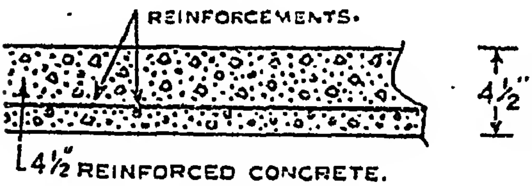
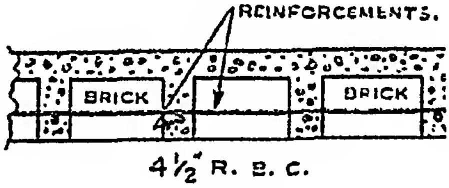


Figure 7.



Figures 4 & 5 are sections of $4\frac{1}{2}''$ cement concrete and $4\frac{1}{2}''$ Bonded Brick Concrete roads.

Figures 6 & 7 are sections of $4\frac{1}{2}''$ R. C. and $4\frac{1}{2}''$ R. B. C. roads.

The cost of concrete roads has been considerably reduced by introducing bricks, a cheap material, in the lower part of the concrete, the concrete at top taking all the wear and tear.

The cost of $4\frac{1}{2}''$ cement concrete of proportion (1:2:4) per 100 sq. ft. works out as follows:—

Stone chips-34 cft. @ Rs. 40/- per 100 cft.	= Rs.	13	10	0
Sand-17 cft. @ Rs. 15/- per 100 cft.	= Rs.	2	8	0
Cement-6¾ bags @ Rs. 2/8/- per bag.	= Rs.	16	14	0
Labour.	= Rs.	3	6	0
Cost per 100 sft.	= Rs.	36	6	0
Cost per 100 cft.	= Rs.	97	0	0

Whereas the cost of 4½" B. B. C. with 10"×5"×3" bricks—1½" apart with 1½" concrete on top works out to :—

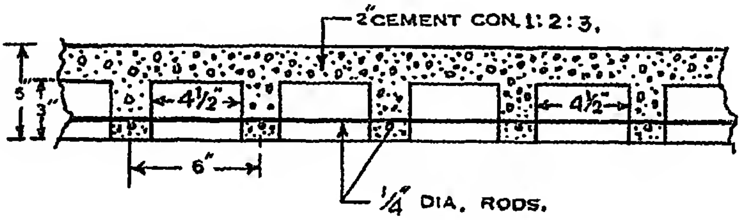
Bricks—200 @ Rs. 18/- per 1000 including laying	=Rs.	3	10	0
Concrete in joints and on top—21 cft. @ Rs. 97/- per 100 cft.	=Rs.	20	6	0
	=Rs.	24	0	0

The comparison shows that the cost of 4½" cement concrete works out to Rs. 36/6 per 100 sft. whereas 4½" Bonded Brick Concrete costs only Rs. 24/- *i.e.*, about 2/3rds the cost of the concrete. The greater is the quantity of bricks inside the concrete the greater will be the saving in cost. It is clear on the very face that when we introduce a material as bricks worth Rs. 15/- to Rs. 20/- per 100 cft. inside the concrete, a material worth Rs. 80/- to Rs. 100/- per 100 cft. very great economy is effected in the resultant bonded brick concrete structure.

The actual construction of Bonded Brick Concrete roads, both plain and reinforced, has proved that this form of construction produces very sound, durable and economical concrete roads. These roads are equally efficient like all concrete roads but are much less costly. *When the cost of maintenance is taken into consideration they are probably cheaper than any other kind of road construction now in use in India.*

1. I started laying a length of 700 ft. of 5" R. B. C., road in May 1930, at Yehiapur Road, Allahabad. 5" R. B. C., was made by combining 3" deep bricks (9"×4½"×3") with 2" top concrete and 1½" joints between the bricks. Reinforcements used were ¼" dia. rods 6" apart along the length of the road and 10½" apart crosswise (see fig. 8). The proportion of concrete was 1:2:3 with Sankargarh sand stone ballast. The work was done according to author's directions by Allahabad Municipality and Messrs. Mackenzies Ltd. of Bombay were the contractors. The work in 1936 is in a satisfactory condition. Thus six years have already passed. A very large volume of rain water finds its way out into the Jumna from that road. So whenever there is a very heavy shower water flows over the road surface to a depth of about 2 ft. or so with great velocity. Formerly water-bound macadam was used every year and that was washed out by the rushing water during heavy rains. The road as constructed at present is quite satisfactory. Except at some expansion joints between the slabs there had been no other damage. Those joints had been repaired with asphalt concrete. It is to be noted that upper concrete has not separated from the lower brickwork and the whole thing has worked like one mass of 5" depth.

Figure 8.



Expansion joints were used every 16 feet apart and the surface was treated with soda silicate (1 in 4) wash. There had been some cracks at

the middle of the slabs which had been repaired with asphalt. The subgrade was old road bed and that was in many places ordinary earth and in some places old road metal. Ordinary common Allahabad bricks—9″ × 4½″ × 3″ were used. The cost was Rs. 42/12/-per 100 sft.

In April 1932, the Chief Engineer, P. W. D., Bengal, tried some experimental lengths of 6″ R. B. C., 6″ B. B. C. and 6″ R. B. A. C. roads at the 5th mile of Calcutta-Jessore Road (just near Belgachia railway overbridge). The present conditions of those Calcutta Roads in June 1936, is perfectly satisfactory—just like 7″ all-concrete road laid from Belgachia Tram Depot upto that place. Wooden sign-boards had been fixed against each experimental length and they can be inspected now.

In these cases 10″ × 5″ × 4″ bonding bricks had been used.

2. *Experiment No. 1—6″ R.B.C.*

4″ thick bricks with top 2″ concrete and 2″ joints between the bricks filled up with the same concrete.

Reinforcements—3/8″ dia. rods—7″ apart along length and 12″ apart crosswise—placed 1″ above bottom.

Proportion of concrete—1 : 1½ : 3 (Pakur stone ballast—¾″ to ¼″ gauge used).

Expansion joints— 30 feet apart.

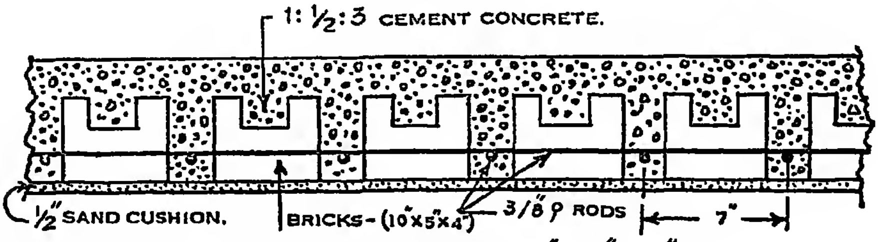
Surface treatment— 3 coats of soda silicate wash 1 in 4 (after 3 weeks of setting).

Width of slab—18 feet.

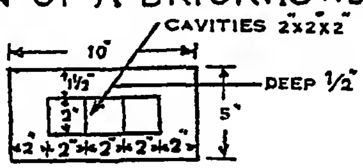
In this experiment, reinforcement had been used at the bottom and not at the top. The slab has stood quite satisfactorily for the last 4 years without any sign of deterioration.

Present condition of the road is ideal (June.1936). Figure 9 shows the section.

Figure 9.



PLAN OF A BRICK.10″x5″x4″.



There are no cracks in the slab and there had been no troubles whatsoever in the same. Its behaviour is just like an all-concrete slab. The top surface being cement concrete it cannot be distinguished from an all-concrete slab. In outside appearance both R. C. and R. B. C roads are quite similar. (See details in Plate No. R/1.)

Note—R=Reinforced, B=Bonded, B=Brick, C=Concrete, A=Asphalt.

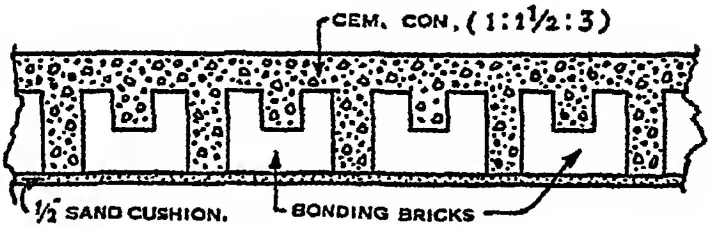
3. Experiment No. 2—6" B.B.C. road.

Particulars same as experiment No. 1. (See Plate No. R/1). No reinforcements used.

Bricks laid break-jointed crosswise with 2" joints between them. (See Fig. 10.)

Figure 10.

Section along road.



Length of slab—30 ft.

Preparation of bed old road bed scarified and regraded.

Constructed—April, 1932.

Present condition—(June 1936) quite satisfactory.

Two fine expansion cracks developed which had been patched up with asphalt.

It is to be noted that in this case no reinforcement had been used whereas in the first experiment reinforcement had been used. Both the slabs are standing quite satisfactorily. In this slab two fine cracks developed whereas in the other no cracks developed. It appears that the reinforcing rods prevented the appearance of cracks in the first slab, otherwise there is no difference between the two.

4. Experiment No. 3—6" R.B.A.C. (Reinforced Brickwork Asphalt Concrete).

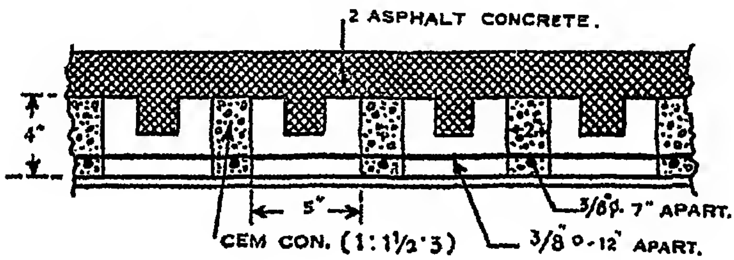
4" R.B.C. at bottom with 2" grouted asphalt concrete surfacing. (See Plate No. R/1).

Here particulars of the lower 4" R.B.C. is like experiment No. 1 and the 2" of the cavities of the bonding bricks had been filled up with grouted asphalt concrete.

Asphalt used—17 lbs. per sq. yd. (See Fig. 11.)

Figure 11.

6" R. B. A. C.



Constructed in April 1932.

Present condition (June, 1936)—Excellent.

This experiment showed that a Bonded Asphalt Concrete surfacing on a R. B. C., foundation makes an excellent road. The foundation and the surfacing worked together as one mass.

5. In 1933, Municipal Engineer, Benares, tried a $4\frac{1}{2}''$ R. B. C., surfacing in the Water Works Main Road of the Benares Municipality.

Here the proportion of concrete used was—1 : 2 : 4 with stone ballast and Gaya sand.

Area covered—761 sq. yds.

Cost—Rs. 1633-11-6.

Cost per sq. yd.=Rs. 2-2-4.

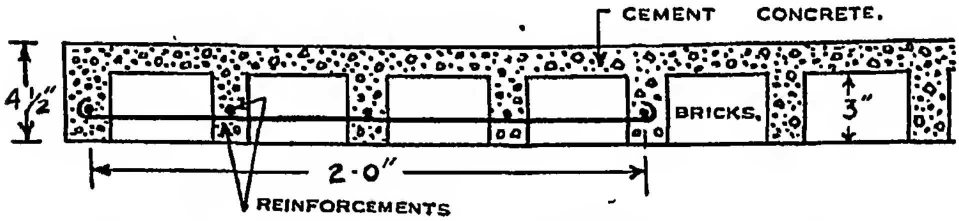
Here reinforcing rods were used at the edges only and not in the central part.

Expansion joint—30 ft. to 36 ft. apart.

Constructed—1933.

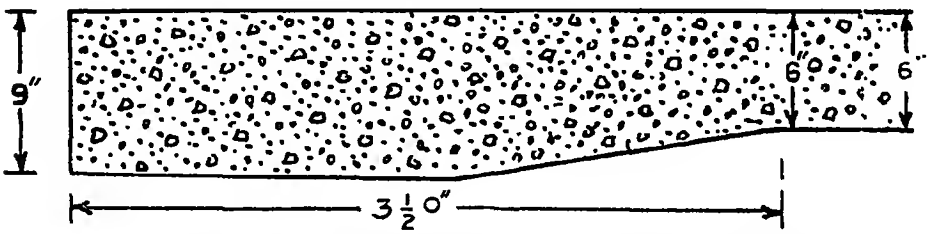
Present condition in June 1936—Excellent (See Fig. 12).

Figure 12.



It is to be noted here that in concrete roads the edges are usually made thicker than the central part. For 6″ concrete road the edges are made 9″ thick. For a 5″ concrete road the edges are made 7″ thick. (See Fig. 13.)

Figure 13.

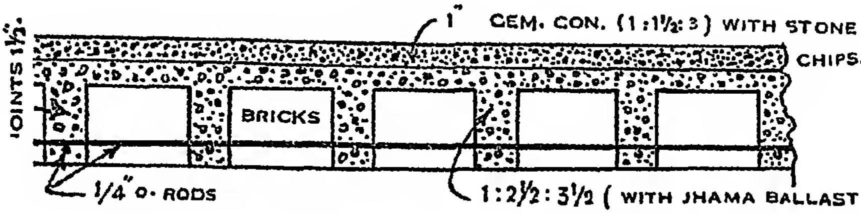


In the present case instead of thickening the edges a little reinforcement had been provided and the road is standing for the last three years quite satisfactorily.

6. In August 1933 another road was constructed at Benares at Nepal Raj Palace called Kaisar Castle. Here two course concrete was used. That was a 5″ R. B. C., road. 3″ bricks with $1\frac{1}{2}''$ joints and 1″ top, cement concrete.

($1:2\frac{1}{2}:3\frac{1}{2}$) concrete with jhama ballast (which is cheap but not so hard) was used at the bottom and the top 1" ($1:1\frac{1}{2}:3$) was laid with stone ballast. Figure 14 shows a section.

Figure 14.



Chunar sand stone was used in the work. The present condition of the road is quite satisfactory.

The experiment shows that economy in R. B. C. road can be effected by using a cheaper ballast with weaker proportion of concrete below and a richer proportion of concrete with stronger and costlier stone ballast at the top. The cost of jhama ballast was Rs. 13/- per 100 cft. whereas the cost of stone ballast was about Rs. 30/- per 100 cft. So by using jhama ballast concrete of $1:2\frac{1}{2}:3\frac{1}{2}$ economy was effected.

7 & 8. In 1934, the Chief Engineer, Calcutta Improvement Trust made two experimental lengths of 7" R. B. C. at Jaggannath Ghat Road each 32 ft. long and 17 ft. wide. Figure 15 and Figure 16 are the sections.

Figure 15.

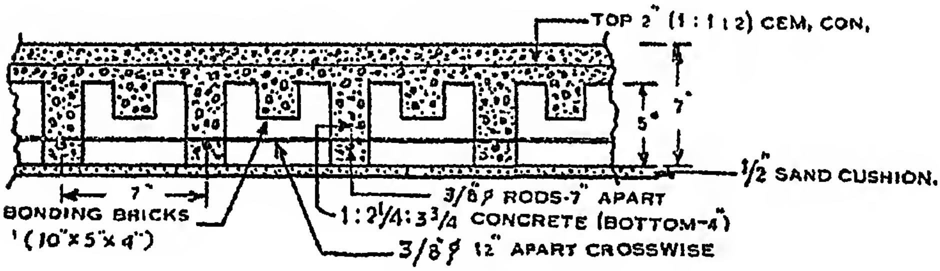
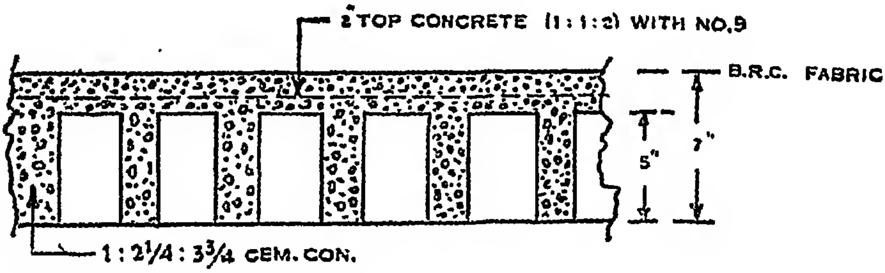


Figure 16.



Bottom concrete—$1:2\frac{1}{4}:3\frac{3}{4}$.

Top concrete—$1:1:2$.

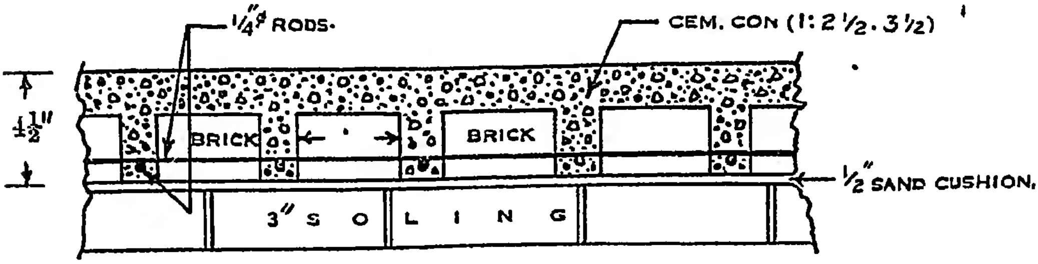
Present condition in June 1936—Excellent.

The sections had been laid along with 7" R. C. road.

It is not possible now to find out which is R. B. C. and which is R. C. Both have cement concrete facing on the top and look alike. They are standing the wear and tear just alike. (See Plates $\frac{II}{6}$ & $\frac{II}{7}$ for detail.)

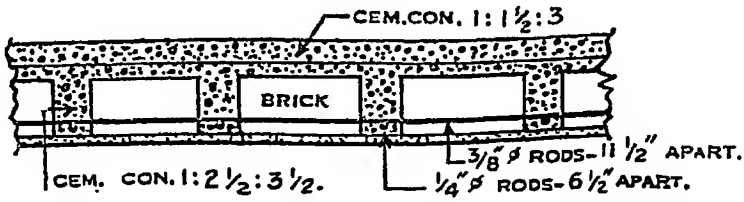
9. In September 1934 a $4\frac{1}{2}''$ R. B. C. surfacing was laid on a new road bed at Telinipara (Bhadreswar Municipality). That was done in connection with the widening of the Mill Road for a length of about 500 ft. That was done with $4\frac{1}{2}''$ R. B. C. with $\frac{1}{4}''$ dia. rods 7" apart along length and 12" apart crosswise with the proportion of concrete as $1 : 2\frac{1}{2} : 3\frac{1}{2}$ with stone ballast. The present condition of the road in June 1936, is quite satisfactory. Figure 17 is a section of the road.

Figure 17.



10. Hospital Road at Barisal was covered with $4\frac{1}{2}''$ R B. C. in April 1934 according to author's design and specifications. $4\frac{1}{2}''$ R. B. C. road was made by using 3" deep bricks with $1\frac{1}{2}''$ joints with 3/8" dia. rods $11\frac{1}{2}''$ apart across the road and $\frac{1}{4}''$ dia. rods $6\frac{1}{2}''$ apart along the road. Cement concrete with picked jhama ballast of proportion $1: 2\frac{1}{2} : 3\frac{1}{2}$ was used in the joints between the bricks and $\frac{1}{2}''$ above the bricks and the remaining 1" was done with richer cement concrete $1 : 1\frac{1}{2} : 3$ with hard Pakur stone ballast ($\frac{1}{2}''$ gauge and down). Fig. 18 shows a section of the road.

Figure 18.



A length of 500 ft. was done with $4\frac{1}{2}''$ R. B. C. at a cost of Rs. -/4/5 per sq. ft. or Rs. 2/8/- per sq. yd.

The condition of that road in June 1936 is perfectly satisfactory. The maintenance cost in these two years was practically nil. The municipal supervisor informed the author that the maintenance cost of about 800 ft. of R. B. C. road was Rs. 5/- only for filling up the expansion joints with tar and pitch.

11. The Barisal Municipality then laid $4\frac{1}{2}''$ R. B. C. at the Sadar Road, opposite Hospital, for a lenghth of about 300 ft. under the same specifications at a cost of Rs. -/4/6 per sq. ft. That was constructed in December 1934 and the present condition in June 1936 is ideal.

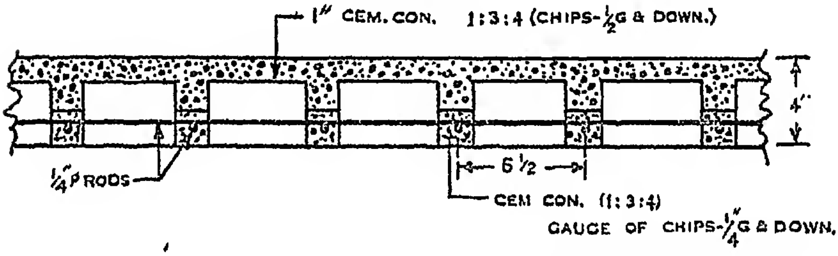
12. A $4\frac{1}{2}''$ R. B. C. road was constructed at Burranagore (North of Calcutta) in Bengal Immunity Laboratory Roads in 1935 with $\frac{1}{4}''$ dia. rods as reinforcements $6\frac{1}{2}''$ apart along length and $11\frac{1}{2}''$ apart crosswise. Proportion of concrete was $1 : 2 : 3$. The present condition of the road in June 1936 is ideal. In one part of the road there was a depression during construction and that was repaired later with another layer of concrete about $\frac{1}{2}''$ thick after 2 days. That repaired concrete did not stand but started peeling off.

13. In April 1936, the Collectorate Road at Barisal was laid with $4\frac{1}{2}''$ R. B. C. according to the same specification as the Hospital Road of Barisal. The length of the road was 1500 ft. and width 12 ft. 6 in. That is the main road from Steamer Station on the river side to the town. The traffic is the heaviest in that part.

14. Another $4\frac{1}{2}''$ road is now in progress known as the Chowk Bazar Road. The length of the road will be over 2,000 feet and width 12 ft. 6 in. The specification is the same as that of Hospital Road. The present tender rate as accepted by the Municipality is annas 4 per sq. ft. (See Plate $\frac{x}{5}$ for detail).

15. In Areadah Municipality a 4" R. B. C. surfacing with $\frac{1}{4}''$ dia rods as reinforcements was done at Satish Mallick Lane, Areadah. The proportion of concrete was 1 : 3 . 4. There is foot traffic only. Figure 19 is longitudinal section of the road. It is to be noted that the proportion is 1 : 3 : 4.

Figure 19.



The present condition of the road in June 1936 is excellent.

The Chief Engineer, P. W. D., U. P. tried a 200 ft. length of 5" B. B. C. with 3" brick with $1\frac{1}{2}''$ joints and 2" topping with cement concrete of the proportion 1 : 2 : 3. No reinforcement was used 4" jhama ballast was rolled in for the subgrade. Expansion joints were used 20 ft apart. The road was constructed at the end of December 1935. The present condition of the road in June 1936 *i.e.*, after six months is quite satisfactory. (Plate No. $\frac{x}{8}$ shows detail). Appendix No. I shows a tabulated statement of Bonded Brick Concrete roads (B. B. C. and R. B. C.) constructed, with particulars of constructions and their present conditions.

How to make different depths of B. B. C. and R. B. C. roads.—Usually sizes of common bricks in India are $10''\times5''\times3''$ and $9''\times4\frac{1}{2}''\times3''$. The former size is in Bengal and in some other places and the latter size is in Bihar, U. P., Punjab etc.

We shall consider $10''\times5''\times3''$ bricks first.

- 3" — a brick flat.
- 4" = a brick flat and 1" cement concrete.
- $4\frac{1}{2}''$ = a brick flat and $1\frac{1}{2}''$ cement concrete.
- 5" = a brick flat and 2" cement concrete or a brick-on-edge.
- 6" = a brick flat and 3" cement concrete or two bricks flat with a mortar joint, or a brick-on-edge with 1" cement concrete.
- 7" = 2 bricks flat with a mortar joint and 1" cement concrete, or a brick-on-edge and 2" cement concrete.

8" = 2 bricks flat with a mortar joint and 2" cement concrete.
9" = 2 bricks flat and 3" cement concrete.
etc. etc. etc.

In case of 9"×4½"×3" the different depths of roads can be arranged as done above.

Often it is convenient to burn special bricks as 10"×5"×4" and use the same.

Bonding Bricks.

4" depth = a brick flat 4" deep.
5" depth = 4" brick and 1" cement concrete.
6" depth = 4" brick and 2" cement concrete.
7" depth = 4" brick and 3" cement concrete.

10"×5"×4" bonding bricks can be manufactured easily at a cost of Rs. 14/- or so per 1000 or so.

Bonding bricks of other shapes and sizes can be manufactured and used in B. B. C. and R. B. C. roads.

Plate No. 5 shows B. B. C. and R. B. C. of different depths.

Often it is more economical to use special bonding bricks in road construction. 5" and 6" bonded brick concrete roads are very common. These can be made very conveniently with 10"×5"×4" bonding bricks. Figures 20 and 21 show sections of 5" and 6" B. B. C. roads.

Figure 20.

(5" B. B. C.)

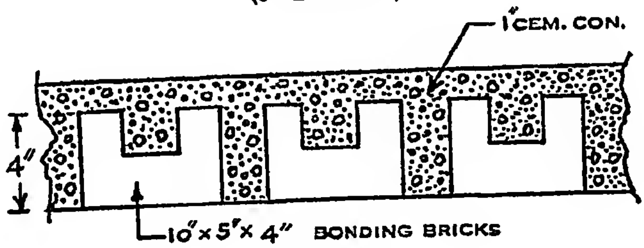
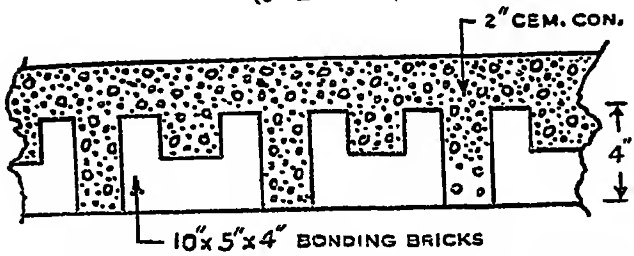


Figure 21.

(6" B B C.)



R. B. C. Vs. R. C. *The strengths of R. B C. and R. C. slabs with the same depth, same proportion of concrete, same age, same reinforcements are the same for all practical purposes.* Figs. 22 and 23 show sections of two R. B. C. and R. C. slabs subjected to bending. In both cases the tensile stresses developed are taken by the bottom steel and compressive stresses at top by the concrete at top. So theoretically the strength and stiffness should be the same. Experiments have shown that they are practically the same. The author's

paper on Comparative study of R.B., R.B.C. and R.C. had been accepted and published by the Institution of Engineers (India). The paper deals with that problem.

Long series of experiments on reinforced brickwork were conducted by the writer between 1916-1922 at Patna New Capital Works and at Benares Hindu University construction. The results of these experiments have been published in the writer's book on "Experimental Researches on Reinforced Brickwork".

In 1917, a very interesting set of experiments on R. B., R. B. C. and R. C. beams under the same conditions of spans, sections, reinforcements, method of loading were tested by the author at Patna. These are the experiments Nos. 5 6,7,8 and 9 in page 3 of the aforesaid book. See Plate No. $\frac{8}{3}$ for the details.

From experiments 8 and 9 we find that R. B. C. beam is equally stiff and strong as R. C. beam. So their methods of calculation for determining their strengths will be similar. In both cases tension was taken by the steel rods at the bottom and maximum compression by the cement concrete at top. Comparing experiments Nos. 5 and 7, we find that by using 2 : 1 mortar in the brickwork the strength of R. B. beam was not increased over that with 3:1 mortar. The results also show that in experiments 5, 6 and 7 the R. B. beam. had deflected much more than in experiments 8 and 9 showing thereby that the stiffness of R. B. C. and R. C. beams is greater than that of R. B. beams. With low percentage of steel the difference of strength between R. B. and R. B. C. or R. C. is very small say within 5% to 10% of the strength. On working out the stresses in steel and brickwork with the values of modulus ratio $\frac{E_s}{E_b} = 36$ for R. B. and $\frac{E_s}{E_c} = 15$ for R. C. and R. B. C. The results are as follows :—

Expt. No.	Kind	m	Calculated stress in steel at failure—lbs. per sq. in.	Calculated stress in brick-work or concrete at failure.	Max. B.M. In-lbs.
5.	R.B.	36	49,000	890	172,274 In. lbs.
6.	R.B.	36	50,000	890	179,376 „ „
7.	R.B.	36	48,000	855	172,274 „ „
8.	R.B.C.	15	48,000	1130	181,576 „ „
9.	R.C.	15	49,500	1150	184,576 „ „

On working out the calculated failure stress for these R. B., R. B. C. and R. C. beams we find that the failure tensile stress varied between 48,000 to 50,000 lbs. per sq. in.

These experiments clearly prove that with low percentage of steel there is not much difference between the load bearing capacity of R. B., R. B. C. and R. C. beams and slabs.

Again referring to experiments 50 and 51 of the same book we find 7" R. B. C. Vs. 7" R. C. slabs on 12 ft. span with same depths and reinforcements.

7" R. B. C.= 6" brick plus 1" cement concrete

Expt. No.	Particulars	Span	depth	Eff. depth	width	reinfts.	percentage of Steel.	Ext. load	deflection at centre.
50	7" R. B. C.	12"	7"	6.6"	23"	8 ¼" dia	.23	41 cwt. 50 ,, 55.1 ,,	.3 .12 Failure
51	7" R. C.	12"	7"	6.6"	23"	8 ¼" dia	.23	41 cwt. 50 ,, 56 ,, 58 ,,	.3 .41 .5 Failure

From these loads and deflections we see that R. B. C. and R. C. slabs deflected to the same extent with the same loads and R. C. slab failed with 58 cwt. whereas R. B. C. failed with 55.4 cwt.

Expt. No.	Particulars	Values of m.	Max. B.M.	Tensile stress in steel (calculated)	Compressive stress in concrete
50	7" R. B. C.	15	In. Lbs. 115,356	Lbs. per sq. in. 60,500	Lbs. per sq. in. 1350
51	7" R. C.	15	151,723	64,500	1140

These results support the statement that R. B. C. is practically equally stiff and strong as R. C. slab. For the design work the values of modulus ratio and safe stress of concrete at top will be taken as the same in both cases.

Plate No. 5 shows a chart of the load and deflection curves of the comparative experiments on R. B., R. B. C. and R. C.

We come to a very important conclusion from these experiments that— R. B. C. and R. C. possess equal strength and stiffness but R. B. C. is much cheaper than R. C. So in order to effect economy in road construction R. B. C. can be safely adopted in the place of R C. For example 6" R. B. C. Vs. 6" R.C., roads-reinforcements—3/8" dia. 6½" apart one way and 11½" apart crosswise in both cases. Figures 22 and 23 show the sections.

Figure 22.

(6" R. B. C.)

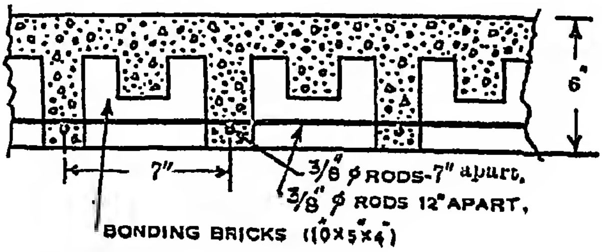
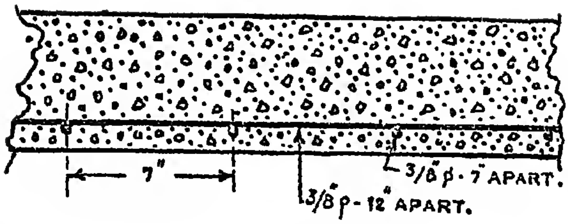


Figure 23.
(6" R. C.)



Analysing the quantities we find the cost as follows :—

Per 100 sft.—(Taking Lucknow rates).

6" R. B. C.

Bricks—200 @ Rs. 14/- plus Rs. 3/- per 1000	=	Rs.	3 4
Cement concrete in joints = 11 cft. } 29 cft. @ Rs. 100/-			
Cement concrete at top = 18 cft. } per 100 cft.	=	Rs.	29.0
Reinforcing rods— 1 cwt. @ Rs. 8/- per cwt.	=	Rs.	8.0
		Rs.	40.4

6" R. C.

Cement concrete = 50 cft. @ Rs. 100/- per 100 cft.	=	Rs.	50/-
Rods—1 cwt. @ Rs. 8/- per cwt.	=	Rs.	8/-
		Rs.	58/-

So for the same strength and stiffness 6" R. C. slab will cost Rs. 58/- per 100 sft. whereas 6" R. B. C. slab will cost only Rs. 40.4. There will be a saving of about 40% in the cost over R. C. and these roads will stand equally well for years.

Concrete Vs. R B. C.

Bonded Brick Concrete is the same concrete with bricks introduced into the lower part of the concrete. The upper concrete possess the same tensile and compressive strengths in both cases. In case of lower part the brick and concrete possess between 2/3rds to ¾ths of the strength of all concrete.

The strength of the brickwork can be taken as half of that of concrete. In B. B. C. 30 to 45% of the lower part is in concrete. So the equivalent strength of the lower part = 30 to 45% of concrete plus $\frac{70}{2}$ to $\frac{65}{2}$ of equivalent concrete. Thus strength of lower part will be 65 to 77.5% of concrete, or 2/3rds to ¾ths of the strength of all-concrete.

Often cement concrete without reinforcements is used for the road construction. B. B. C. can be used in preference to the cement concrete and effect thereby a great economy.

5" C. C. Vs. 5" B. B. C.

Figure 24.
(5" Cement concrete.)

(5"CEMENT CONCRETE.)

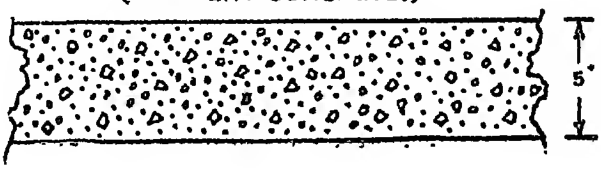
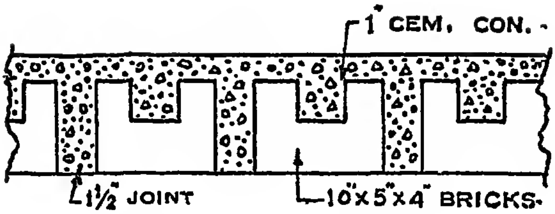


Figure 25.
(*5" B. B. C.*)



Cost of 5" C. C. $= \frac{5}{12} \times 100$ @ Rs. 100/- per %	... Rs.	42	0 0
Cost of 5" B. B. C.—			
10" × 5" × 4" bricks—200 @ Rs. 18/- per 1000	... Rs.	3	10 0
cement in concrete in joints and at top—21 cft. @ Rs. 100/- per % cft.	... Rs.	21	0 0
	Rs.	24	10 0

The comparison of cost for 5" C. C. Vs. 5" B. B. C. is Rs. 42/- Vs. Rs. 24/10/-.

Concrete Vs. R. B. C.—It is more economical to use R. B. C. in the place of cement concrete for the same strength.

The strength of the concrete is measured by its resisting moment. The resisting moment of 4", 4½", 5", 5½", 6", 7", 8" concrete slabs per ft. width are as follows:—

$$M = \frac{bd^2}{6} \times f = \frac{12d^2}{6} \times 60 = 120d^2.$$

Where b = width = 12".
d = depth of slab in inches.
f = safe tensile strength of concrete in lbs. per sq. in.
= 60 lbs. per sq. inches.

Plain cement concrete.	Resisting moment per ft. width $= 120d^2$ for concrete.	Resisting moment per ft. width for brick concrete. $= \frac{3}{4}$th of concrete
4"	1920 In. lbs.	1440 In. lbs.
4½"	2430 In. lbs.	1823 In. lbs.
5"	3000 In lbs.	2250 In. lbs.
5½"	3630 In. lbs.	2723 In. lbs.
6"	4320 In. lbs.	3240 In. lbs.
7"	5880 In. lbs.	4410 In. lbs.
8"	7680 In. lbs.	5760 In. lbs.

(*Strength of R. B. C.*)

Resisting moment $= A_t f_t a.$

$= A_t \times 16000/- \times \frac{7}{8}d$

$= A_t \times 14000/- \times d = 14000\, A_t d.$

Where A_t = Sectional area of steel in sq. in per ft. width of slab.

f_t = Safe stress of steel in lbs. per sq. in.

= 16000 lbs. per sq. in.

a = lever arm in inches.

d = effective depth in inches.

R. B. C.	Eff. depth.	Resisting moment per ft width = 14000 A_td.
		approximately
4″ with 3/8″ dia rods 7″ apart.	3″	8064 in. lbs.
„ with 5/16″ dia rods 7″ apart.	3″	5472 „ „
„ with ¼″ dia rods 7″ apart.	3″	3528 „ „
4½″ with 3/8″ dia rods 7″ apart.	3½″	9408 „ „
„ with 5/16″ dia rods 7″ apart.	3½″	6384 „ „
„ with ¼″ dia rods 7″ apart.	3½″	4146 „ „
5″ with 3/8″ dia rods 7″ apart.	4″	10752 „ „
„ with 5/16″ dia rods 7″ apart.	4″	7296 „ „
„ with ¼″ dia rods 7″ apart.	4″	4704 „ „
6″ with 3/8″ dia rods 7″ apart.	5″	13430 „ „
„ with 5/16″ dia rods 7″ apart.	5″	9120 „ „
„ with ¼″ dia rods 7″ apart.	5″	5880 „ „
7″ with 3/8″ dia rods 7″ apart.	6″	16128 „ „
8″ with 3/8″ dia rods 7″ apart.	7″	18816 „ „

Total depth.	Reinforcements.	Eff. depth.	Resisting moment per ft. width = 14000 $A_t d$.
4″	3/8″ dia. 12″ apart	3″	4704 In. lbs.
,,	5/16″ ,, ,,	,,	3192 ,, ,,
,,	¼″ ,, ,,	,,	2058 ,, ,,
4½″	3/8″ ,, ,,	3½″	5428 ,, ,,
,,	5/16″ ,, ,,	,,	3724 ,, ,,
,,	¼″ ,, ,,	,,	2401 ,, ,,
5″	3/8″ ,, ,,	4″	6372 ,, ,,
,,	5/16″ ,, ,,	,,	4256 ,, ,,
,,	¼″ ,, ,,	,,	2744 ,, ,,
6″	3/8″ ,, ,,	5″	7840 ,, ,,
,,	5/16″ ,, ,,	,,	5320 ,, ,,
,,	¼″ ,, ,,	,,	3430 ,, ,,
7″	3/8″ ,, ,,	6″	9408 ,, ,,
,,	5/16″ ,, ,,	,,	6384 ,, ,,
,,	¼″ ,, ,,	,,	4116 ,, ,,
8″	3/8″ ,, ,,	7″	10976 ,, ,,
,,	5/16″ ,, ,,	,,	7448 ,, ,,
,,	¼″ ,, ,,	,,	4802 ,, ,,

The resisting moment of 6″ concrete slab per ft. width is 4320 In. lbs. The resisting moments of 4½″ R. B. C. with ¼″ dia. rods 7″ apart one way and 3/8″ dia. rods. 12″ apart crosswise are 4146 In. lbs. and 5428 In. lbs. in crosswise directions. Calculations for R. B. C. are usually done by ignoring tensile strength of the brick concrete. In reality the tensile strength of the concrete or brick concrete plays some part. These calculations show that a 4½″ R. B. C. is stronger than a 6″ cement concrete road. This section of road has been extensively used at Barisal with excellent results. At Barisal the subsoil water level comes to within a foot from the surface of the road during rainy season and thus a strong foundation is necessary for such roads. The cost of 4½″ R. B. C. is much less than the cost of 6″ cement concrete.

Cost per sq. ft.

6″ cement concrete per % sq. ft. = 50 cft. @

Rs. 100 per 100 cft. = Rs. 50 0 0

4½″ R. B. C.

Bricks—200 @ Rs. 18 per 1000 = Rs. 3.6

Cement concrete—21 cft.

@ Rs. 100 per 100 cft. = Rs. 21 0

Rods—2/3rd cwt. @ Rs. 7/8 per cwt. = Rs. 5.0

Rs. 29.6

Say Rs. 30/-.

Cost of $4\frac{1}{2}''$ R. B. C. is Rs. 30/- whereas the cost of 6" cement concrete is Rs. 50/-. That shows great economy of R. B. C. over cement concrete roads.

Position of reinforcements.—It will be interesting to find out what is the most suitable place for putting the reinforcement in concrete and bonded brick concrete roads. Some suggest that reinforcement should be used at bottom only, some at the top only and some both at top and bottom.

In the 5th mile of Calcutta-Jessore Road 6" B. B. C., and 6" R. B. C., were tried side by side, one without reinforcements and the other with reinforcements. Both are standing well. 6" B. B. C., has developed two fine expansion cracks in the slab whereas in R. B. C., there are no cracks. That shows that one of the functions of reinforcement is to prevent appearance of cracks. The length between the expansion joints can be increased by using reinforcement.

At Jaggannath Ghat Road 7" R. B. C., road experiments—reinforcement has been used in one case at the bottom and in the other case at the top 2" below the surface and in both cases these roads are standing perfectly satisfactorily.

If we look to pages 32-33 of the *Indian Concrete Journal* of the February issue of 1934, we find under the head "Recent Practical Developments, American Road Builders' Association"—Current practice in the design of state highway concrete pavements—that the reinforcing fabrics or bars are used 2" to 3" below the top surface of the roads (2" in case of New Jersy, Ohio, Pennsylvania, Victoria, and $2\frac{1}{2}''$ for New York and so on). The depth of the concrete usually varied between 6" to 8".

Thus according to the latest American practice the reinforcement is used at the top and not at the bottom. The reinforcement at the top will prevent the appearance of cracks at the top surface. The cracks due to surface tension, caused by the temperature stresses, will be better prevented by the use of reinforcing rods or fabrics at the top. In case of weak foundation reinforcement at bottom will be more effective.

Reinforcement.—

(1) $\frac{1}{2}$ cwt. per 100 sq. ft. where there is good foundation below—as $\frac{1}{4}''$ dia. rods—$6\frac{1}{2}''$ apart along length and $11\frac{1}{2}''$ apart crosswise will make $\frac{1}{2}$ cwt. per 100 sq. ft. That may be used preferably $1\frac{1}{2}''$ to 2" below the top surface.

(2) One cwt. per sq. ft. where the foundation is not so good. That may be used at bottom only.

(3) $1\frac{1}{2}$ cwt. per sq. ft. ($\frac{1}{2}$ cwt. at top and one cwt. at bottom) where the foundation is very defective. 3/8" dia. rods—7" apart along length and 12" apart crosswise at bottom will make one cwt. per 100 sq. ft. and at top $\frac{1}{4}''$ dia. rods 7" apart along length and 12" apart crosswise will make $\frac{1}{2}''$ cwt. at top.

Figure 26.

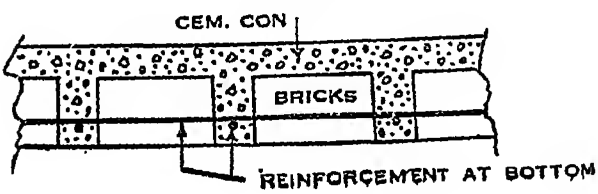


Figure 27.

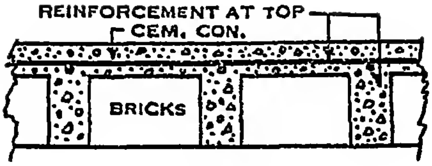
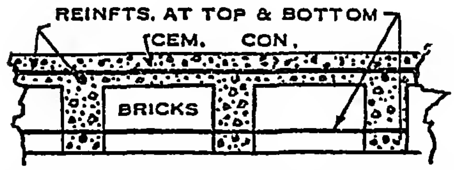


Figure 28.



Figs. 26, 27 and 28 show sections of R. B. C. roads reinforced at bottom, at top and at bottom and top.

1. *Method of construction.*—The existing surface of the road is to be levelled properly and rolled. All pits are to be filled up and unevenness removed by the use of some metal and consolidating the same with a road roller. Usually a camber of 1 in 60 is given in the road section.

In cases of new roads a brick soling or 3" or 4" brick jhama or stone road metal is to be used and consolidated by rolling.

2. ½" sand is to be spread on the surface and wetted well with water.

3. Net work of reinforcing rods. ¼", 5/16", or 3/8" dia. (as required), 6½" or 7" apart one way and 11" or 12" apart crosswise (according to the size of bricks 9"×4½"×3" or 4", 10"×5"×3" or 4") is to be spread on the road bed 1" above the sand. The joints can be made 2" or 1½" or more as desired.

4. Wet, overburnt first class bricks are to be spread inside the network. The size of bricks in Upper India is usually 9"×4½" whereas the size of the net will be 11"×6½". Thus the joint will come out to be 2". In case of 10"×5" bricks, as in Bengal, the net will be 12"×7". The joints are often made ½" also for the sake of economy.

5. Sprinkle a little water on the bricks, grout in a little mortar (1 : 2½), about ¼" thick in joints and pour in wet cement concrete of plastic consistency in the joints upto 1½" or 2" depth so that the concrete finds its way easily down. Pack the concrete well. Graded ballast of ½" down to 1/8" may be used for bottom 2" concrete. The grouting can be omitted for good plastic concrete (1 : 2½ : 3½).

6. Place stiffer concrete of proper mix on the top to the required depth and consolidate the same well by tamping as is done in case of concrete roads. Too much water must be avoided for the top concrete. 5 to 6 gallons of water per bag of cement is usually required.

7. Cover the surface with wet gunny bags for 24 hours and after that make certain bunds at intervals of 4 feet; put wet earth or sand or moss or straw etc., inside the bunds and water the same well for two to three weeks,

8. Treat the surface well with three coats of sodium silicate wash (1 in 4 solution) at intervals of 24 hours after a period of two weeks.

Three inches of extra concrete with double rods are to be used both at edges and at expansion joints. Expansion joints are to be provided at every 20 ft. to 30 ft.

In case of concrete with brick or any soft ballast, it is advisable to paint the surface with ½" to 1" road board tar or asphalt, with necessary grits or sand, to take the surface wear and tear. In such cases the concrete surface is to be cleaned with copious water with the help of a broom 4 to 5 hours after laying of the concrete so as to remove the laitance on the surface. First of all a coat of bituminous emulsion is to be used on the wet surface within 24 hours and after that tar or asphalt surfacing is to be laid when the slab has set and the surface is dry.

6" R. B. C. road with ¼" to 3/8" dia. rods is used for ordinary heavy traffic.

5" R. B. C. roads with ¼" to 3/8" dia. rods are used for ordinary medium to heavy traffic.

4½" R. B. C. roads with ¼" to 3/8" dia. rods are used for light to medium traffic of moffusil town roads.

4" R. B. C. roads with ¼" dia. rods is to be used for light traffic.

It must be clearly understood that the concrete must be of very good quality, properly laid, of rich proportion with hard ballast, clean coarse sand and good Portland cement. If fine sand is used or weak proportion adopted for the surface, there is very little chance of success of the concrete roads. Selection of materials for concrete, proper gauging of water for plastic consistency are essential for the success of the road construction.

Cost of B. B. C. and R. B. C. roads—The cost of B. B. C. and R. B. C. roads will vary from place to place according to the cost of labour and materials, according to the proportion of concrete, depth of the road, quantity of concrete and bricks in the same.

The cost of bricks vary considerably from place to place. The approximate cost of 1000 bricks—picked first class (in 1936) :—

Calcutta—Rs. 18/- per 1000 (10"×5"×3").

Lucknow—Rs. 9/- per 1000 (9"×4½"×3").

Benares—Rs. 12/- per 1000 (10"×5"×3").

Calcutta—Rs. 24/- per 1000 (10"×5"×4").

Lucknow—Rs. 14/- per 1000 (10"×5"×4").

For working out costs we shall assume cost of rich cement concrete (1 : 1½ : 3) with stone chips at Rs. 110/- per cft.

Ditto with jhama chips (1 :2½ :3½) at Rs. 65/- per 100 cft.

(Cost of reinforcing steel rods—@ Rs. 7/- per cwt.)

Cost of $4\frac{1}{2}''$ R. B. C. road as adopted at Barisal per 100 sq. ft.

Preparation of subgrade by picking up bed, scarifying, regrading, re-rolling complete with $\frac{1}{2}''$ sand at the top	Rs.	3	8	0
Picked first class hard burnt bricks including labour for laying—200 No. @ 17/- per 1000 ...	Rs.	3	6	0
Cement concrete in joints and $\frac{1}{2}''$ above the bricks with picked jhama ballast of gauge $\frac{1}{2}''$ and down (1 : $2\frac{1}{2}$: $3\frac{1}{2}$)—$12\frac{1}{2}$ cft. @ Rs. 65/- per % cft.	Rs.	8	2	0
1″ cement concrete (1 : $1\frac{1}{2}$: 3) with Pakur stone ballast ($\frac{1}{2}''$ gauge and down)—$8\frac{1}{3}$ cft. @ Rs. 110/- per 100 cft.	Rs.	9	3	0
Mild steel rods—2/3 cwt. @ Rs. 7/- per cwt. ...	Rs.	4	11	0
Expansion joints and three coats of sodium silicate—(1 in 4) –per 100 sft.	Rs.	1	8	0
	Rs.	30	6	0
Cost per sq. ft. ...	Rs.	0	4	10

The accepted tender for the work was 0/4/6 per sq. ft. and over $\frac{1}{2}$ mile of $4\frac{1}{2}''$ R. B. C. road was constructed at that rate at Barisal.

Cost of different sections can be worked out on similar lines.

Maintenance—Bonded Brick concrete roads, plain and reinforced, are cheap in initial cost and require very little maintenance cost, say Rs. -/4/- per 100 sq. ft. in a year. A comparative statement of cost of different kinds of roads including maintenance is given in appendix No. 2. The statement clearly shows that the Bonded Concrete roads, plain and reinforced are cheaper than other kind of roads now in use in India.

Further investigations on Bonded Brick Concrete roads, plain and reinforced, for further reduction of the cost.

It has been found from the experiments by the author that weak proportion of cement concrete such as with proportion of mortar 1 ; 4, 1 : 5, 1 : 6, or so can be used safely in reinforced concrete works. The method is to use rich cement mortar or concrete to embed the bottom rods and on the top weak proportion of cement concrete is used and the two layers are interbonded with brick keys. Fig. 29 is a section of reinforced brick weak cement concrete slab. We shall call this R.B.W.C. road. Fig. 30 is a section of B.B.W.C. road.

Figure 29.

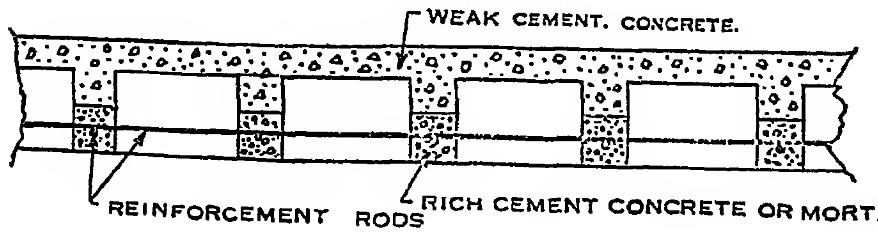
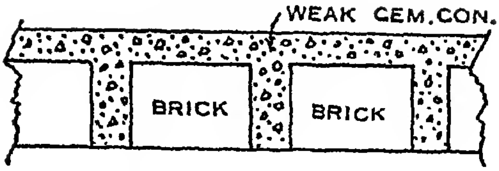


Figure 30.



Experiments had shown that the addition of lime increases the workability and strength of weak proportion of cement concrete. Full details of experiments can be seen in author's book on "Experimental Researches on Reinforced Brickwork Lime Concrete slabs".

In this way the cost of B. B. C. and R. B. C. roads can be further reduced but it is to be noted that the weak proportion of cement concrete will not stand the abrasion due to road traffic. The application of soda silicate wash on the surface will greatly increase the surface strength of such roads. On the top surface asphalt or tar painting with necessary stone grit can also be done. A wearing course of rich cement concrete can be used on top for taking up the wear and tear.

In some Hyderabad State road Mr. Zaman tried 1 : 1 : 5 : 8 (c : l : s : b) concrete for the side portion (excluding the central part) of a road and that stood quite well for two years ; when it showed signs of abrasion, the road surface was then painted with Colas and grit. In R. B. W. C. roads similar procedure can also be adopted. Then comes the question of adhesion of the tar or asphalt painting on the concrete surface. The question has been investigated by several engineers. It has been found that if after 4 to 6 hours of laying the concrete, the surface is washed with a copious supply of water and a stiff broom, the scum on the surface will disappear and a rugged surface will be produced. Pieces of ballast will be protruding out from the bed of the concrete. A coat of bituminous emulsion is to be laid within 24 hours after washing ; so that the bitumen may stick well with the ballast. After the cement has set, the painting with tar or asphalt with hard stone grits and sand can be done. In that way the adhesion of painting with the concrete base will be thoroughly ensured. The wear and tear will be taken by the surface painting and the weak concrete below will not be exposed to wear and tear.

Bonded Brick Concrete for Hilly places. In hilly places often good bricks are not available. In such cases stone bricks or blocks are to be used in the place of common bricks. In hilly places stone bricks or blocks or boulders are very cheap and these can be used in the subgrade in the place of bricks. Other particulars are similar to those described before. See plate No. $\frac{II}{10}$ for details.

Further particulars of $4\frac{1}{2}''$ R. B. C. roads actually constructed have been given in the plate No. $\frac{II}{9}$.

Different thicknesses of Bonded Brick Concrete roads, plain and reinforced have been shown in plate No. $\frac{II}{2}$.

Plate No. $\frac{II}{1}$ shows some of the different types of roads with concrete, bonded concrete, bonded brick concrete, (plain and reinforced), bonded brick weak cement concrete (plain and reinforced), bonded brick lime concrete (plain and reinforced), reinforced brickwork asphalt concrete (plain and reinforced), bonded concrete or weak cement concrete or lime cement concrete base.

On the whole there is an immense field for research in bonded concrete roads, plain and reinforced and the economical results obtained so far bode a very good future for these roads. On account of economy with efficiency, these roads will solve to a large extent the road problem of India and in a few years we may find a few thousand miles of these roads in this country.

Specifications.

(*for 1½" R. B. C. roads*).

BARISAL.

Bricks..........Picked first class (hard-burnt).

Straight picked jhama selected will also do.

Cement.........Portland cement of British Standard Specifications.

Indian cements as, Rohtas, Swastika etc., will do.

If quick-setting cement is wanted for the last few bays Rohtas-crete or Swastika-crete can be used there.

Sand...........Clean, coarse sand, graded in size will be used.

For the lower course, half part local savar sand half part coarse sand will do.

For the top 1" concrete only, coarse sand to be used.

Rods...........Mild-steel rods. A rod can be doubled without fracturing the outside fibres at the bends.

Jhama chips. Of picked brick jhama of gauge ½" down to 1/8". The ballast is to be washed clean of dust before use.

Stone chips....Hard stone chips as Pakur etc., will do. The gauge will be ½" down to 1/8". The ballast is to be washed clean.

Measure........Cement in bags is one cwt. and in volume it is to be kept as 1¼ cft. (90 lbs. per cft.). While giving contract this is to be specified. That is the procedure also according to the latest Code of practice for reinforced concrete. Cement is to be measured by weight and not by volume. One bag=1¼ cft.

Water.......... 4 to 6 gallons of water are required per bag of cement. If the ballast and sand be wet 4 to 4½ gallons will be found to be ample. The top concrete is to be made a bit stiffer.

Time...........The top 1" concrete is to be laid within ½ hour after the laying of the bottom layer.

List of Plates.

DISCUSSIONS ON PAPER No. 35.

Mr. A. K. Datta :—Mr. Chairman and Gentlemen,—I have much pleasure in presenting to you my paper which is based on my researches during the last 13 years. I started my investigations in reinforced concrete and brickwork as early as 1916 under Mr. Brebner at Patna, who was then Executive Engineer there (now Chief Engineer, Government of India). First of all, we used reinforced brickwork in buildings. Later on when the question of corrosion of rods came in we combined concrete with brickwork and introduced this R. B. C. (reinforced brick concrete) in building construction. We found afterwards that this material was very suitable for road construction. We tried this on many roads carrying different kinds of traffic—both light and heavy—and it proved very satisfactory. The bricks are placed at intervals of two inches and cement concrete is placed on the top and in the joints so that the whole thing—bricks and the concrete in the joints and at the top work together as one mass. The upper concrete does not separate from the main body of the slab. This type of construction has one advantage over all concrete; it costs much less than an all-concrete construction of the same thickness, because, as you all know, bricks are the cheaper than cement concrete. We have made several trials with reinforced concrete since 1930. At Lucknow it was tried on the University Road opposite Canning College eastern gate in December 1935. I went there the day before yesterday to have a look at the road, and I saw the part on which much of the traffic passed but did not find any cracks or any sign of deterioration. It is just like an all concrete slab. In other parts of Lucknow they have concrete tracks of the thickness of six inches, but here we used three inches bricks spaced one and half inches apart with two inches of concrete at the top. We take special care about this brick concrete, and where the expansion joints come in we provide some extra concrete at the ends. As regards the extent to which we could go about the depth of the top surfacing, I may say that formerly many of us must have seen that when we laid bricks quite close and put cement mortar both in the joints and on the top that cement mortar did not peel off. I made some similar construction here in 1928 and I find that even with a thin surfacing we did not find any such separation in 1937. In our road construction I have tried with one inch topping—I have given some details in the paper—and I think we can go still further. You have seen at Unao that the amount of abrasion in those roads during the last 6 or 7 years was only ¼ inch or less. If we find that the use of one inch concrete in the upper surface has not abraded to that extent in 6 or 7 years we can reduce the top cement concrete still further. In my paper I have given a list of actual constructions we have made. We have tried this in Bengal—on the Calcutta-Jessore Road, which Mr. Mitchell saw I think. It was constructed in April 1932, and it is now in a perfectly good condition. Then we have tried this on the Jaggannath Ghat Road. I suggested to the Chief Engineer of the Calcutta Improvement Trust who was laying concrete roads there to try my system, and he readily agreed to try it and to use those bricks with cavities. That road was constructed two years ago It is now in a perfectly good condition. The traffic is very heavy there. It would be interesting to discuss the right position of reinforcements for slabs subjected to heavy traffic. I have given my views in my paper, that where the foundation is good we can provide reinforcements at the top, but where the foundation is defective we can provide some at the bottom and some at the top or at the bottom only.

The next thing which I would like to tell you and which I have not discussed in my paper but which has been raised by several engineers is about the co-efficients of expansion of bricks and concrete. The co-efficients of expansion

of bricks and concrete are practically similar. For bricks we take the co-efficient of expansion as 0.0000055 and for concrete it is 0.000006. They are practically similar. If you just look above at the ceiling of this hall you will find that the slabs are all R. B. C. slabs. If you scrutinise them carefully you will find not a single crack anywhere. As regards warping, we all know that in the case of these concrete slabs the ends warp out but when the same is bounded with a layer of bricks below warping stops.

I have laid special stress in my paper on three points:—

(i) Necessity of a cheap supply of cement;

(ii) Necessity of cheap transport;

(iii) Necessity of bonded brick concrete where we replace the maximum quantity of concrete by bricks at the bottom.

So that a combination of these three may reduce the cost of Bonded Brick Concrete practically to the cost of ordinary road macadam. If we can do that we can say that a time will come when we shall be able to do 1000 miles of concrete road every year. At present we have got barely 250 miles. In my paper I have suggested that we want the cost of cement to be Rs. 25/- per ton. I am glad to inform you—it is good piece of news for road engineers—that new cement factories are under construction at Dehri-on-Sone and Charkhi Dadri, and the Managing Directors have told me to declare before this Congress that in January next they would be able to supply cement at Rs. 25/- a ton f.o.r. factory. I recently met the Managing Director at Delhi and I got still better terms. He offers cement now at Rs. 23/- per ton f.o.r. factory for road works. Now that we are going to get cement at this rate, I hope the Government of India and the Railway Board would reduce the cost of transport. If they reduce the cost of transport we can get cement cheaper still and with our cheap method of construction we shall be able to produce concrete roads at 50 per cent of the present cost.

Chairman:—Would any member like to speak on this paper?

Mr. K. G. Mitchell (Government of India):—The Congress is trying to standardize expressions. The word "subgrade" in paragraph 1 is I think incorrectly used. At page 125 of the paper Mr. Datta has given us some indications of the traffic for which his various specifications are suitable. On looking through the paper this morning I cannot find any statistics of traffic in regard to any of the experiments which he has mentioned in the paper. He has told us that by the use of bonded brick concrete we can use a much thinner concrete surface than otherwise would be possible, *i.e.*, the whole benefit lies in bonding. But if you look at the figures 14, 15 and 16 on page 113 and figure 18 on page 114 you will see that he seems to propose to lay one-inch concrete slabs in separate layers not bonded with the concrete below. This suggests that he thinks that an inch of concrete by itself is sufficient. He also said in the paper that in weak foundations reinforcements should be used at the bottom. I should like to ask him why? If the foundation is weak there is no more reason why it should be supported at the edge of the slab than at some middle points Actually, though it may sound a heresy, I am disposed to think that the best place to place reinforcement is in the middle. I would like to ask Mr. Datta: supposing, having read his paper, I go off tomorrow and try to follow his suggestions and make reinforced brick roads, how much would it cost me in royalties?

Mr. N. Das Gupta:—Mr. Chairman and Gentlemen,—I must congratulate Mr. A. K. Datta on his excellent paper, but I would like to draw your attention

to the table given in Appendix 2 of his paper giving a comparative statement of the cost of roads including repair costs. Columns 7 to 9 of the table are taken from the publication of the Concrete Association of India about comparative costs. You will find that the initial cost of bituminous grouted wearing surface has been shown as Rs. 26/- per 100 square feet and the average maintenance cost as Rs. 3/6/- per 100 square feet every year. The engineers of the Public Works Department present here know how far this statement is correct. Referring to page 44 of Mr. Dean's paper (No. 34). We find that the cost of 2½" grouting was Rs. 2/6/- per square feet or Rs. 26/2/- per 100 square feet. So far so good. Now, regarding maintenance we find the total up-to-date cost is only Rs. 810 over a period of nearly four years. The total length of the stretches is half a mile and we may take the average width as 16 feet; so that the maintenance of an area of 42,200 square feet was only Rs. 810 or Rs. 2/- per 100 square feet for a period of four years. So that the average maintenance cost comes to only eight annas per 100 square feet per annum and not Rs. 3/6/- per 100 square feet. I would only request the Cement Concrete Association to give facts and not exaggerated statements.

Mr. Arifuddin (Hyderabad):— Mr. Chairman and Gentlemen,—we have all read with great interest Mr. Datta's Paper on Bonded Brick Concrete Roads. The United Provinces and Bengal are favoured by nature in the matter of good soil for brick, but unfortunately the Deccan and particularly Hyderabad, is not favoured by nature in this matter. Our bricks are perhaps the worst in India. But God has given us plenty of good stones and good lime. I feel that the alternate for us lies in the use of stones. I should like the author of this paper to enlighten me whether he considers the use of stone slabs about 1 to 2 feet with joints filled up with cement concrete to be quite as satisfactory as brick or small stones.

In Hyderabad Nawab Ahsan Yar Jung, the Chief Engineer, Drainage Department, has built a road with lime and cement concrete. I noticed that though from the point of view of the wearing capacity of the material it was not much of a success, there was not a single crack on this road; which showed that even lime concrete 6 inches thick with a little mixture of cement can bear the pressure of ordinary traffic. As such I feel that if we have a 3 inches or 4 inches weak cement mixture overlaid with one inch, 1½ inches or 2 inches of rich mixture, there is no reason why the road should not be successful. I should be obliged if Mr. Datta will give his opinion on this question and also on the possibility on the layers ever separating from each other.

Professor Raja Ram:—Mr. Chairman and Gentlemen,—Mr. Datta in introducing his paper had remarked that the co-efficient of expansion he had taken for bricks was 0.0000055, he also said that the co-efficient of expansion for cement concrete steel was nearly equal to this figure. I would like to ask Mr. Datta on what basis he has taken the co-efficient of expansion of bricks. Has he himself made any experiments? Or has he taken the figure from the American Civil Engineers' Pocket Book? I may say that in my opinion, the co-efficient of expansion of bricks depends upon the nature of the material from which bricks are made and also upon the range of temperature at which they are burnt. We cannot put at the same figure the co-efficient of expansion of all bricks made from Kashmir to Cape Comorin. There is no such thing as a standard brick in India. In England there is blue staffordshire.

I would also like to ask Mr. Datta if he has taken into consideration the factor known as Poisson's ratio into account in his calculations of Reinforced

Brickwork structures ? Can he give me a figure for Poisson's ratio for Reinforced Brickwork ?

Mr. W. A. Radice :—Mr. Chairman and Gentlemen,—I have not given this paper the study it deserves, but from a rather superficial reading of the letter press and examination of the diagrams it seems that the reinforced brick road proposed has very little vertical shear value. There are vertical planes of weakness in shear in all directions.

I should like the author to tell us whether the test stretches of his road surfacing described by him were laid on existing roads, whose surfaces have been consolidated for years or whether any of them were laid on a newly constructed embankment without any soling beyond that provided in his designs and cost data. I ask this question because test surfaces laid on old metalled surfaces seem to me rather to beg the question. They are laid on a strong foundation already provided free of cost.

Mr. A. K. Datta (Author):—Mr. Chairman and Gentlemen,—as regards Mr. Mitchell's observations, my reply is as follows. In the case of bonded brick concrete, with the cement concrete surfacing it produces sound and economical concrete road where the subgrade is of bricks down below with which the surface concrete is interbonded, by extending ribs of concrete into the joints, between the bricks. The word "subgrade" is not properly used. As regards traffic figures, they are given in the paper. On the Yahiapur Road (Allahabad) the traffic is about 200 tons a day. Formerly whenever there was a heavy shower water flowed over the road surface to a depth of about 2 feet or so with great velocity. Formerly a coat of water-bound macadam was used every year and that was washed off by the rushing water during the rains. The road as constructed at present is quite satisfactory. Then on the Hospital Road in Barisal the traffic is about 500 or 600 tons a day. On the Jaggannath Ghat Road it may be about 4 to 5 thousand tons a day. On the Collectorate and Chowk Bazar Roads the traffic is about 800 tons a day. I think Mr Mitchell referred to thin concrete surfacing at the top. Where the cost of stone is very high this is a satisfactory way of reducing the cost.

As regards the position of the reinforcements, we tried the experiments mentioned in the Concrete Journal on the Jaggannath Ghat Road. In one of the experiments the reinforcement was used at the bottom and in another at the top. Of course, both are standing the traffic equally well.

As regards Mr. Das Gupta's remarks about the maintenance cost, of course I took the figures from the Concrete Association's reports.

A member :—These figures are ten years old ?

Mr. A. K. Datta (Author):—Yes. Even taking the lower figure we find that the maintenance cost of concrete road is much lower than any that we have.

Mr. Arifuddin has said that good bricks are not available at Hyderabad. I have also taken that point into consideration during my investigation. In hilly places we find ballast very cheap and bricks of very poor quality. What we do in such places is—I have given some figures in the paper—in diagram No. $\frac{11}{15}$—we insert boulders in the place of the bricks. I agree with Mr. Arifuddin that he can use stone blocks in the place of bricks and reinforce them properly and provide expansion joints at regular intervals. As regards the use of the big slabs with reinforcements, I have also got this thing in view. I have made some experiments, and it would be a good thing if this Congress gives me some

money to make experiments further and report the results at the next session. As regards his remarks about lime and cement, this problem has been vexing me for the last seven years. I do not say I have been completely successful, but I have partly succeeded. We tried lime with molasses and used the molasses as a binder for lime concrete. It hardens very considerably, and it still further hardens when it is treated with sodium silicate. If we mix up about 10 per cent of molasses with lime concrete we will find that the strength is cent per cent greater and if we treat the surface with sodium silicate we will find that the surface will be hardened by another 25 per cent or more. We are just making further experiments on those lines.

As regards the co-efficient of expansion of bricks and concrete, I leave it to you to see. The roofing of this hall was constructed sometime back, and you will find not a single crack anywhere. We have constructed any number of slabs, and we do not find any separation between the brick and the concrete.

Chairman:—It is now time for me to thank Mr. Datta on your behalf for his interesting paper which has resulted in such an interesting session. I do not propose to take up much of your time, because the time left at our disposal is now very short and you have got two other papers to discuss, but I do wish to enter a mild caveat against the yard stick of progress advocated by Mr. Datta which appears to be the rate of progress of concrete roads. This yard stick should, in my opinion, be something like the rate of improvement of our roads to such standards as would carry the traffic that is likely to develop on them in the not too remote future.

CHAIRMAN:—Rai Bahadur S. N Bhaduri.

Chairman:—I now call upon Mr. Sondhi to introduce his Paper.

The following paper was then taken as read:—

Paper No. 37.

INDIAN "ROAD-AGGREGATES", THEIR USES AND TESTING.

BY

R. L. Sondhi, I.S.E.,

Executive Engineer, Public Works Department, Punjab.

Note—Quotations in this paper are from (1) High-way Engineers' Hand-book by Harger & Bonney, (2) "Road Aggregates," by Knight and are annotated accordingly where the text does not make the source clear.

Object of the Paper.—A very useful article, on attrition tests on stones used as road metal in India, by Mr. M. S. Krishnan, M.A. Ph.D., appeared in the Records of the Geological Survey of India, Vol. LXIX, part 3, 1935. It was reproduced in the magazine "Indian Roads" of April 1936.

This paper is intended to offer comments on the contents of that article, from the point of view of the road engineer, to make a brief comparison of

the properties of the various stones, so far tested at Alipore Test House, in relation to their use in water-bound macadam, bituminous or concrete roads and to compare those stones with stones regarded as good in other countries. Suggestions are also made for conducting further more detailed and more systematic researches in the properties of road aggregates available in this country.

Mr. Krishnan's Paper is mainly an abstract in tabular form of the results of the attrition and specific gravity tests on road stones carried out at the Alipore Test House since 1924. His conclusions (summarised at Appendix 1) on the relative qualities of stones, based on the results of petrological examination are of a very general nature and apply, mainly, to the use of these stones in water-bound macadam. Although an extensive milage of this type of road surface will exist for a long time to come, regard must also be had to the increasing recent use of bituminous and cement concrete surfaces to meet the difficulties brought about by fast motor traffic. The special behaviour of stone aggregates in such surfaces has not been considered by Mr. Krishnan.

With the ever increasing demand for improved roads and their increasing milage means must be devised to carry out their construction and maintenance with economy. The economy to be really effective must be applied to the biggest item of the bill. Aggregate constitutes that item and actually carries the traffic. It is, therefore, incumbent on the road engineer to apply scientific research to "road-aggregates" and to use only such as will for a particular specification give the longest service at the minimum initial and repairs cost.

QUALITY OF AGGREGATE FOR DIFFERENT KINDS OF ROAD SURFACES.

The first thing to decide is the qualities desired in aggregates employed for the different classes of road surfaces now constructed in India and the next to find out from results, so far ascertained, how far the desiderata are obtained in the aggregates available in this country.

Let us, therefore, consider the requisites of each class of surface seriatim :—

(1). *WATER-BOUND MACADAM.*

The water bound milage in British India consists of :—

40180 Miles of stone metal and

17383 Miles of 'Kankar' or laterite.

Kankar and soft laterite roads, though very dusty, stood up fairly well to the traffic of former days but now deteriorate rapidly. The reason is that the bullock-cart grinds the metal to dust. In pre-motor days it remained to a large extent on the road surface but now is sucked out by fast traffic and is blown away.

(a) *Physical properties required in an aggregate for a water-bound macadam road.*

To cope with the natural and mechanical destructive agencies, to the extent possible, stone for use in the surfacing of this class of road should be sound, hard and tough to withstand the abrasive action of iron-tyred bullock-cart traffic and the vibratory action of high speed-motor vehicles. It should

also possess high crushing strength and cementing power and should not contain any soft materials that are likely to disintegrate rapidly under the influence of weather conditions. These qualities are rarely found together in any high degree. Thus flint, though hard, is often brittle, and some schistose or slaty rocks, although hard and tough when quarried, often disintegrate when exposed to weather. The quality of cohesion is rarely found in combination with extreme hardness and toughness. Material well consolidated and united in mass, resists crushing much better than when loose, and good binding property enables a stone comparatively weak to bear better than a harder stone which does not bind. The relative values of stone are determined by certain physical tests described below.

Common Physical Tests.

Abrasion or Hardness Test.

Hardness is the ability to resist direct abrasion. It is tested in what is called the Dorry Machine by grinding a cylinder of the stone 25 centimetres in diameter on a cast iron disc with a pressure of 25 grammes per square centimetre, rotated at 30 revolutions per minute using crushed quartz as an abrasive. The loss in grams per 1,000 revolutions is measured and the quality is expressed by the *co-efficient of hardness*.

$h=20-\frac{W}{3}$ where h is the co-efficient of hardness and w the loss in grams per 1,000 revolutions. A good lime stone will show a value of h of 12 to 15, and granite and trap of 15 to 19. According to B. H. Knight (The Road Makers' Liberary Vol 3), "For good stone the hardness should be 17 or above, from 17 to 14 the stone is considered to be medium quality, while a figure below 14 indicates a stone which is too soft for roadstone. It has been found that the differences shown by this test for different stones do not necessarily agree with the practical experience of the behaviour of stones under traffic."

The Page Impact Test for toughness.

Toughness is the ability to resist impact. A cylinder 25 millimetres in both length and diameter has the impact from a 2-kilogramme hammer transmitted to its end through a steel block with a spherical bearing. The blows start with a fall of 1 centimetre and which is increased by 1 centimetre for each blow. The height of the last blow in centimetres is taken as the measure of toughness. Lime Stones usually range from 10 to 15, granite 15 to 20 and trap 20 to 40. This test is, according to Mr. Knight, "The most informative and significant of mechanical tests and goes a long way to indicate the value of a stone for road-making purposes especially if considered in conjunction with the results of the Deval Attrition Test. A high class road-making stone will withstand nineteen or more blows under this test; but for some traffic conditions an impact of sixteen or eighteen is permissible."

Attrition Test with the Deval Machine.

This is a combined wear and impact test made by placing a washed and dried sample weighing 5,000 grams and consisting of 50 fragments in a cast-iron cylinder 20 by 34 centimetres in diamensions, set at 30 degrees with a shaft and rotated at 30 revolutions per minute for 10,000 revolutions. The sample is again washed, dried and weighed. The percentage loss of weight called the *per cent wear*, is taken as the measure of the wearing qualities of the stone. The *French Co-efficient* of wear was formerly much used and is still frequently specified.

$$\text{F. C.} = \frac{40}{\text{loss of weight per cent}}$$

A maximum per cent of wear of 7 or a minimum F.C. of 6 is usually required for water-bound macadam stone.

Crushing (or compressive) Strength Test.

This is made on cubes or cylinders and "any apparatus may be used which has compression shackles designed to ensure an axial loading of the test specimen." (2). A cylinder 2 inches in diameter by 4 inches in length should give a value of at least 10,000 pounds per square inch on a stone having a per cent of wear less than 7.

Cementation Test.

Cementing value is of special importance in macadam stone. It is tested by grinding the stone with distilled water in a ball mill and moulding the resulting paste into cylinders 25 by 25 millimetres. These are dried and then broken by the impact of a 1 Kilogramme hammer falling 1 centimetre. The number of blows is the criterion. Sandstone shows little cementation, limestones 25 to 300 and trap 100 to 800. A minimum of 25 is usually required.

Specific gravity Test.

The chief utility of this test is in connection with the identification of the stones. Moreover, from it the weight per cubic foot of volume can be calculated. The specific gravity of rock ranges from about 2.6 to about 2.9.

Water-absorption Test.

"The significance of this test is the measurement of the amount of pore space in the rock, and hence it is in some way a measure of the weakness of the rock, since pores are a source of weakness under traffic ; though this test is not as significant as the more mechanical ones indicating the physical properties of stone. In most cases a rock which has an absorption of more than 1 pound of water per cubic foot of stone, should be rejected, unless considerations of the other tests taken as a whole indicate otherwise. The test is of more importance when choosing a sedimentary rock than an igneous one." (2). The results, so far, obtained show that "The strength of certain stones diminishes after continued exposure to wide ranges of temperature and frost, and that for stones which are submerged under water the strength decreases as the porosity increases, while the finer-pored stones are the weakest." (2).

The above described tests have been indicated in Mr. Krishnan's Paper ; but he has described only the Attrition Test and the results tabulated by him refer only to this test and the specific gravity of the rocks.

Further physical Tests.

In addition to the more commonly used tests, described above, the following are of value and some of these have been introduced only recently and have yet to establish their efficacy.

Fracture Test.

This is conducted under geological test with a hand lens. "Stone suitable for water-bound macadam should crush in cubical shapes rather than in thin, flat pieces, and preferably with rough jagged fracture so that it may interlock firmly under action of the roller." Angularity or otherwise of the edges of the individual constituents is a most important characteristic to examine when choosing a stone for use as macadam and chippings. Further, in some rocks the presence can be ascertained of certain coloured minerals which indicate a poor quality. The colours to be looked for are a deep rusty red in granites, which generally

indicates that the micas and felspar are in a fairly advanced stage of decomposition, or a greenish tinge in basalt and dolerites, together with a somewhat earthy appearance, which shows the presence of the undesirable mineral chlorite resulting from the decomposition of the ferro-magnesian minerals." (2).

(2) *Geological Tests.*

These constitute an examination with a microscope and a consideration of the origin of the rock. "Great refinements should be avoided as the general classification is all that is necessary to the road engineer after the physical qualities are ascertained by test." (1).

This Geological classification according to bulletin 31, U.S. Office of Public Roads is given in appendix 2.

"*Interpretation of Tests.*

It has been found impractical to specify definite qualities of stone for use in water-bound macadam. Economy and practical consideration demand that all available sources should be considered. Tests should be made to determine the relative qualities of stone from different sources and the results used as a guide for selection."(1). It will be instructive to review the work done in America and England in this connection and to compare it with the results so far achieved in this country and thereby to get an idea of the work ahead.

Work done in America. (Vide, Highway Engineers' Handbook by Harger and Bonney).

"In the work of the New York State Highway Commission all tests are tabulated geographically, using a county as unit. The table reproduced as appendix 3 is compiled from the records of that Department. It will be noted that comparisons are made in different classifications only, as it is considered that conclusions should not be drawn from a comparison of tests procured from materials having different origins and composed of different minerals. For the purpose of ready comparison a figure known as the "weighted value" has been introduced (see last column of appendix 3). This is computed by giving relative weights of 3 to the French Co-efficient, 2 to hardness, 1 to the toughness values; and adding these together. These relative weights were determined from a consideration of the amount of material used in the different tests and the personal equation of running them. By consulting these tables, the available rocks of different classification in various sections throughout New York State can be determined rapidly, and as new tests are completed they are compared with good average material from that section."

"Any tough, hard-crushed stone which breaks in roughly cubical form and does not air or water slack is suitable for coarse aggregate. Lime-stone granite, gneiss, trap and hard sandstones are generally satisfactory. For class III traffic (300 to 800 daily) it is desirable to use a stone having a French Co-efficient of hardness of 7 or better (6 per cent of wear or less). Stone as soft as 4 French Co-efficient has been used with moderate success, but where a soft stone is necessary because of the prohibitive cost of a better grade the size should be increased. The usual size of coarse aggregate for top course is 1¼ to 2½ inches; for soft stone the size should be 2½ to 3½ inches, using the smaller grades for the foundation course." For purely local roads carrying less than 300 vehicles daily practically any available local stone which does not air or water slack can be used.

"As generally found, trap is uniform in hardness and toughness, making an excellent material for use in top course. Granite and gneiss, where they occur with hornblende replacing a large percentage of the quartz, make an excellent surfacing stone. Quartzites when found in good state of preservation are hard and tough. They should not be confused with crystalline quartz, which is hard but brittle.

Sandstones are extremely variable and only the better varieties should be used.

Lime-stones range from the fine-grained dense products which are hard and tough to the coarse-grained soft products which are not suitable for surfacing."

As regards the work done in England, at the National Physical Laboratory and elsewhere, the theory and practice adopted in that country is as well-described in Volume 3 of Road-makers' Library by Mr. Knight. His conclusions of these tests are summarised as below:—

"*Consideration of the results of the physical tests as a whole.*

In choosing a stone for roadmaking the following figures give a good indication of the test values to be looked for:—

Dorry Abrasion Test	...	17 minimum co-efficient of hardness.
Deval Attrition Test	...	20 minimum French Co-efficient of wear.
Page Impact Test	...	16 blows minimum for macadam.
Crushing Test	...	10,000 pounds per square inch minimum for macadam.
Water Absorption	...	0.6 per cent weight or 1 pound of water per cubic foot of stone.
Cementation Value	...	26 blows minimum.

It is important to remember that the results of the tests as a whole should be taken as indicative of the suitability of a stone for road work, and that even then there may be weakness of structure or composition which are not revealed by the physical tests but which will be shown to be present if the rock is subjected to microscopic examination."

In this connection reference may be made to a paper by L. V. Barton, in which it is suggested that too much importance has been laid on the results of crushing test in the choice of stone. On the other hand the importance of the impact value and the attrition and abrasion figures has been under-estimated. For instance, a stone with a crushing strength of 50,000 pounds per square inch; but with an impact value of say, only 11, is an undesirable stone for use under heavy live loads.

A formula is suggested, namely:

$$\text{QUALITY} = \frac{\frac{a}{100} \times 2b}{c \times d^2}$$

			Maximum	Minimum
Where a represents the crushing strength			50,000	35,000
,, b	,,	impact value	30	15
,, c	,,	abrasion figure	13	20
,, d	,,	attrition figure	4 per cent.	8 per cent
From these values the quality is			144	8.2

A figure of 150 is taken to represent an exceptionally high quality stone, and suggests, as shown in the table, a minimum of 35,000 pounds per square inch for crushing strength and an impact value of 20 minimum for first class stone, with an average wet and dry attrition loss of 8 per cent. These figures are not at all well related to the known behaviour under physical tests, for the number of stones which will resist a crushing strength of 50,000 pounds per square inch must be very few indeed. The use of emporical formula of this kind may be misleading, and in the present state of our knowledge it is safer to compare the results obtained with those given by a few widely used road-stones, the behaviour of which under actual traffic conditions is well-known. The following table is given for purposes of comparison of this kind, and it may be of more use in interpreting the physical tests in terms of the suitability of a given material for use as roadstone, than the table of suggested minimum and maximum values given above:—

QUARRY.	*ROCK NAME.*	*specific gravity*	*Deval test* Average percentage of loss of wet & dry tests.	Abrasion.	Crushing lbs. per square inch.	Impact.	Absorption of water.	*QUALITY.*
Penlee	Hornfels	2.79	1.38		57,207		0 15	Very good.
Bonowe	Granite	2.67	1.84	19.0	35,100	26		
Holthwhistle	Dolorite	2.96	2.85		34,900	21	0.09	Good.
Tonfonaw	Keratophyre	2.90	3.47	17.5		12		
Fife	Dolerite	2.93	12.89	18.1	20,000	16	0.67	Poor.

This table further serves to show how misleading physical tests may be, since the Fife Dolerite is shown to be of high quality with respect to impact and abrasion tests and yet under traffic it has been proved to be unsatisfactory roadstone. In the case of this stone, the test which is of significance is the Deval attrition test, which gives, a truer indication of quality than do the other physical tests. In any case, the results of a number of physical tests of the same stone should always be considered as a whole."

Comparing the above referred to investigations made in the use of stone in water-bound macadam "wearing coats", in America and England with those compiled in Mr. Krishnan's Paper it will be appreciated that we are yet far behind in this pursuit and that work of the geologist, and the road engineer, in India, in this respect needs a greater co-operation. Further investigation and tabulation of stone tests on somewhat similar lines is required. By careful study of the results it may be possible to determine, for Indian aggregates formula for "quality" and "weighted value". Moreover the road engineers all over India may be able to supply a more detailed and reliable information about the aggregate, as a result of careful observation of the actual behaviour of the stones under traffic, which should be tabulated side-by-side with the geological and physical tests. Mr. Krishnan's table may then be expanded on the lines of the American Tables at appendices 2 and 3 and the English ones given above. The general conclusions of Mr. Krishnan for the Indian stones are no doubt generally identical with those

of the English and American authorities for similar stones, but he has not mentioned that his observations are based on the actual experience of road engineers in this country.

(b). Physical properties required in screenings for a water-bound macadam surface.

Screenings act as a filler and binder for water-bound macadam. In their latter capacity they should "puddle" readily under the action of a road roller and water. "Lime Stone Screenings have proved the most efficient as a binder although trap and some other igneous rocks can be bound with their own dust by repeated puddling. Screening consisting mainly of quality have not been used successfully in water-bound construction except by the additions of some lime stone screenings. The use of a percentage of clay or loam as a binder is not admissible except where the cost of lime stone screenings would be prohibitive.

Laboratory methods for testing the cementing power of rock powders are available, but the results obtained are erratic and undependable.

In water-bound roads it is often necessary to mix some lime stone screenings, fine sand loam, or even a small percentage of clay loam with trap, granite, sand-stone, quartzite, or gneiss screenings to get a good bond and prevent ravelling in dry weather."

(c). Physical properties required in stone for "Soling" to water-bound Macadam.

As the soling simply spreads the wheel load transmitted through the wearing coat and is not directly subjected to the traffic action almost any stone that breaks into cubical irregular shapes and is hard enough to stand the action of the roller during construction, will prove satisfactory.

Slate or stone which has weathered from long exposure to the atmosphere is not suitable for "soling". The different varieties may be tested in the same manner as for "Wearing Coat" stone for purposes of selection.

(2) *BITUMINOUS SURFACE TREATMENTS.*

(a) Surface treated with Tar, Pitch, Asphalt or Bitumen.

The essential difference from the ordinary water-bound surface is in the 'paint coat', which forms a thin protective covering which resists wear, prevents dust and water proofs the surface.

In order that this 'paint coat' is effective it should stick well to the water-bound surface below. This will be possible only if the metal of the water bound course and the 'Bajri' or chippings used as grit for the 'paint coat' have requisite 'affinity' for the binder.

The "aggregates" to be suitable for this class of surface should, in addition to satisfying the "physical tests" etc., referred to under water-bound macadam, also possess the property termed in the industry as the 'Bitumen-carrying capacity' of aggregates.

It is well-known that mineral aggregates used in bituminous road construction vary considerably in their power of absorbing bitumens and Reidel has tested the "wetting power" of various binders in contact with various

aggregates by shaking the coated aggregate with water. He classifies by this method different aggregates as 'hydrophilo' or "hydrophobe" according to whether or not the bitumen is displaced by the water. "The following table shows how in general the acidic or basic nature of stones affects its power of adhesion to the binder. It must, however, be remembered that the indication is only general, and that any given stone may give much better or worse adhesion than its petrological class would indicate.

Hydrophilic stones.	*Hydrophobic stones.*
1. Syenite.	1. Basalt.
2. Granite.	2. Greenstone (*i.e.*, decomposed dolerite).
3. Quartzite.	3. Hyperite.
4. Prophyry.	4. Limestone"

While this classification is of interest, "it can hardly be expected to give the whole clue to the problem, since it takes no account of surface texture of the stone." (2). Investigations on this line should be conducted on the stone and chippings or bajri available in this country. The life of a "paint coat" depends mainly, on the rate of crushing of the chips or bajri. The stuff used should, therefore, possess considerable resistance to crushig and the 'chippings' should be of stone, satisfying the corresponding physical test already described. The approved range of size is from 1/8 to 1/4 inch (to pass 3/8 inch mesh). As far as it is known to the author the Alipore Test House has not yet made arrangements for routine test on "Bajri".

(*b*) *Bitumen, Asphalt, Tar or Pitch Grouted Macadam.*

The stone used for this specification must be hard, tough and clean. The coarse aggregate $1\frac{1}{2}$ to $2\frac{1}{2}$ inches size must be uniform and must not contain over 15 per cent of stone smaller than $1\frac{1}{4}$ inches size.

"Under heavy traffic where trap or the harder granites are available, a minimum French Co-efficient of hadrness of 8 is desirable (5 per cent or less of wear). Very good results can be obtained with a minimum hardness co-efficient of 7 (6 per cent or less of wear)" (1), and this is the usual minimum limit where limestones and the harder sandstones are employed. "Under light traffic and where hard rock is very expensive, a co-efficient as low as 5 has been used, but under such conditons it is desirable to increase the size of the coarse aggregate to $2\frac{1}{2}$ to $3\frac{1}{2}$ inches and to use a harder rock for the screening incorporated into the seal coat." (1). Rocks suitable for this work are generally available all over India though particular localities may be deficient in them.

(3) CEMENT CONCRETE OR MACADAM SURFACES.

The essential qualities of the coarse aggregate are that it should be clean, hard and well graded.

"Where trap rock and the harder granites are available, the minimum hardness requirement for crushed stone is generally placed at French Co-efficient of 8 (5 per cent loss of weight). Where the Limestones, hard sandstones and granite hardheads are the most feasible sources of supply, the minimum French Co-efficient can be dropped to 7 (6 per cent loss of weight) with very good results. In exceptional cases a value as low as 6 (7 per cent loss of weight) has been used with moderate success, but anything below 7 is risky for this type of pavement." (1).

Concluding Remarks.

While in India we have not yet progressed beyond conducting the ordinary physical tests on road metals, as carried out at Alipore Test House the road research laboratories in America and England have, in recent years, paid much attention to the influence of such physical characteristics of aggregates as shape, surface texture, mineral composition, absorption, *etc.*

It has been contended that though the attrition tests have been of great service in assisting engineers to make their choice of a material which would improve the water-bound methods of construction, yet they give no criterion of the life of a bituminous or cement concrete pavement.

In concrete where broken stone, brick-bats, etc., are used as the aggregate, abrasion tests would be of no particular value; as the aggregate in this case takes a secondry place, and the cement is of main importance and is carefully tested before use. The cement and sand form the matrix of the concrete, and it is this matrix and that of the bituminous macadam which will be of first importance in their respective road pavement. The aggregate in these cases is a secondry consideration, and has to come into line with the matrix; and if the stone is too hard, a softer material is to be tried.

A theory has been propounded for sometime now that in cement concrete the quality of mix is not influenced by variation in the *quality of the aggregate* so long as the material is sound and durable. This theory lays stress entirely on gradation of the aggregate. Similarly, in the bituminous surfaces the conventional theories of mixture design deal only with the effect of grading.

But it is becoming more and more evident that certain observed differences in the behaviour both of cement concrete and bituminous mixtures can only be accounted for by differences in aggregate characteristics other than gradation.

It has been shown that certain properties of concrete are affected to a marked degree by the kind of aggregate used. Similarly, in bituminous work, experience has shown that certain characteristics of mineral fillers, other than size, greatly influence the stability of the pavement. The significance of the time honoured physical tests for quality of stone, as a real measure of the value of the material as bituminous aggregate, has been questioned.

Therefore, one of the problems confronting users of aggregates for bituminous work at present time is that of devising a more satisfactory routine acceptance test for quality. Engineers in America are, more or less, unanimous in deploring the inadequacy of the routine physical tests, such as the Deval Abrasion Test and the standard toughness test. This had a widespread support of road engineers in that country and has recently received experimental verification through a series of tests on different varieties of crushed stone conducted by Goldbeck. He shows that there is practically no relation between the results of the standard abrasion test and the resistance of those materials to crushing under a roller. These tests were conducted on a circular track 14 feet in diameter constructed in the laboratory. The pavement sections comprising the track were subject either to the action of a roller when testing the aggregate alone, or to a pneumatic tyre when investigating surfacing mixture.

In connetion with roller tests for quality of aggregate, reference should be made to the work done by the Highway Department of Georgia State in the

United States of America. In this case, a hand roller is passed a definite number of times over a layer of the aggregate spread on a metal-lined runway, and the change in size is used as measure of quality.

The circular test track used by Goldbeck is representative of a number of similar devices that have been constructed recently. Equipment of this type possesses great possibilities for the rapid investigation of road paving mixtures. It comes nearer to fulfilling the requirements for an accelerated test than anything yet devised.

Accelerated service tests of the types referred to above while extremely valuable in developing basic data, are obviously not suitable for use as acceptance tests. There was thus the problem of developing a simple, rapid and yet accurate laboratory test, the results of which may be correlated with behaviour under traffic, and which may be used to replace the present unsatisfactory standard physical tests.

Such a result is obtained from what is known as Los Angeles Rattler Test. The method consists in running a 5 Killograms sample of graded aggregate for 500 revolutions in a cylindrical drum 28 inches in diameter and 20 inches in length together with a charge consisting of twelve cast iron shot of the same size and weight as the small shot used in the standard brick rattler. The inside of the drum is provided with a single shelf 4 inches wide extending from end to end.

This test has many obvious advantages over the standard Deval Test. It is much quicker. One such test requires only 5 minutes instead of five hours in case of the other. It is possible to test aggregate of the size used in actual work instead of requiring sample of quarry stone. The effects of impact are much more pronounced, with consequently a much wider spread between the values representing good and poor materials than is the case with the Deval Test. Moreover it appears that the results are independent of the shape of the aggregate particles, which would make it possible to apply the same specification requirements for Bajri and Chippings as for broken stone.

The possibility that the Los Angeles Rattler Test may reveal the necessary information as to the ability of an aggregate to resist crushing under the roller leads to the hope that it may ultimately replace the toughness as well as the abrasion test. If so, it will be a distinct step in advance, not only because it will substitute one method for two, but also because it will then be possible to test all of the usual aggregates *i.e.*, broken stone, Bajri and chippings by the same method.

It will thus be realized that we, in this country, are badly lagging behind other countries in developing a suitable technique for testing our aggregates, which is essential for the economical construction of our roads. There is, however, no cause for desponding ; as in the very near future a test track and road laboratory should be functioning at the Government Test House, Alipore, under the control of the Consulting Engineer to the Government of India (Roads); and by the time of our next annual meeting at Calcutta, we should have gone appreciably ahead with the research in aggregates available in this country. Amen !

APPENDIX 1.

The following is a brief summary of Mr. Krishnan's conclusion in his article referred to in para 1 of this paper :—

(1) A general idea as to the capacity of roadstones to resist wear and tear can be gained from the figures of percentage loss of weight in the attrition tests. The following classification has been adopted by the National Physical Laboratory of England:—

		Percentage loss of weight.	
		Dry Test.	Wet Test.
Very good	...	Up to 2.0	Up to 2.0
Good	...	2.1 to 2.5	2.0 to 3.2
Fairly good	...	2.6 to 3.1	3.3 to 4.0
Rather poor	...	3.2 to 4.0	4.1 to 5.0
Poor	...	Over 4.0	Over 5.0

(2) The best stones for road-making purposes are the medium to fine grained, compact, basic rock with more or less equiangular texture. These include dolerite, basalt, and certain epidorites.

(3) The coarser grained rocks, acid types and compact gneisses come next.

(4) Granulites and hornfelses also occupy a high place amidst road-stones.

(5) The markedly prophyritic rocks are liable to be crushed under load.

(6) The soft rocks like the limestones, shales, laterites and the weathered types of sandstones are not suitable for any but light traffic.

(7) Vein quartz and quartzite (except perhaps some highly ferruginous types) are generally to be avoided.

APPENDIX 2.

GEOLOGICAL CLASSIFICATION AND RESULT OF TESTS ACCORDING TO BULLETIN 31, U. S. OFFICE OF PUBLIC ROADS.

Rock varieties	Per cent wear.	Toughness.	Hardness.	Cementing value.	Specific gravity.
Granite	3.5	15	18.1	20	2.65
Biotite-granite	4.4	10	16.8	17	2.64
Hornblende-granite	2.6	21	18.3	30	2.76
Augite-syenite	2 6	10	18.4	24	2.80
Diorite	2.9	21	18.1	41	2.90
Augite-Diorite	2.8	19	17.7	55	2.98
Gabbro	2.8	16	17.9	29	3.00
Peridotite	4.0	12	15 2	28	3 40
Rhyolite	3.7	20	17.8	48	2 60
Andesite	4.7	11	13.7	189	2.50
Fresh basalt	3.3	23	17.1	111	2.90
Altered basalt	5.3	17	15.6	239	2.75
Fresh diabase	2 0	30	18.2	49	3 00
Altered diabase	2.5	24	17.5	156	2.95
Limestone	5.6	10	12.7	60	2.70
Dolomite	5.7	10	14.8	42	2.70
Sandstone	6.9	26	17.4	90	2.55
Feldspathic sandstone	3.3	17	15.3	119	2.70
Calcareous sandstone	7.4	15	8.3	60	2.66
Chert	10.8	15	19.4	27	2.50
Granite-gneiss	3 8	12	17.7	26	2.68
Hornblende-gneiss	3.7	10	17.1	30	3.02
Biotite-gneiss	3.2	19	17.5	41	2.76
Mica-schist	4.4	10	17.8	30	2.80
Biotite-schist	4.0	...	...	16	2.70
Chlorite-schist	4.2	...	...	24	2.90
Hornblende-schist	3.7	21	16.5	53	3.00
Amphibolite	2.9	10	19.0	29	3.00
Slate	4.7	12	11.5	102	2.80
Quartzite	2.9	19	18.4	17	2.70
Feldspathic quartzite	3.2	17	18.3	21	2.70
Pyroxene quartzite	2.3	27	18.6	17	3.00
Eclogite	2.4	31	17.4	21	3.30
Epodosite	3.6	16	16.0	47	3.03

APPENDIX 3.

Report on Test of Road Stones—N. Y. State Highway Commission, 1914.

COUNTY.		Number of complete tests.	Number of partial tests (no core piece).	Weight lbs. per cubic foot.	Water absorbed, lbs. per cubic foot.	French coefficient of abrasion.	Hardness.	Roughness.	Weighted value.
			CALCAREOUS SANDSTONE.						
Erie	...	5	...	167	0.65	9.5	12.9	13.4	68
Saratoga	...	6	...	169	0.31	10.1	15.9	13.8	76
Steuben	...	4	1	162	1.44	9.4	15.1	13.1	72
			DOLOMITE.						
Clinton	...	6	...	175	0.41	11.9	15.8	12.7	80
Dutchess	...	4	1	174	0.43	12.4	17.3	11.9	84
Essex	...	4	..	173	0.42	13.5	16.9	15.8	90
Franklin	...	4	...	174	0.51	9.5	14.9	12.1	70
Fulton	...	4	...	176	0.15	11.8	16.1	14.4	82
Herkimer	...	17	...	173	0.67	8.4	13.1	6.7	58
Monroe	...	13	2	171	1.07	10.3	14.8	8.2	69
Montgomery	...	8	...	174	0.39	10.6	14.7	11.3	73
Niagara	...	11	...	168	1.50	6.5	14.0	7.0	55
Saratoga	...	8	...	174	0.33	8.6	15.5	9.2	66
St. Lawrence	...	31	...	174	0.65	10.5	15.7	9.9	73
Washington	...	6	...	175	0.29	10.7	15.1	10.5	73
			DOLOMITIC LIMESTONE.						
Dutches	...	8	1	176	0.46	9.0	14.0	10.9	68
Herkimer	...	4	1	170	0.47	11.3	16.7	8.2	76
Montgomery	...	8	1	175	0.41	13.0	15.8	12.4	83
Niagara	...	7	...	166	2.19	9.5	13.1	7.8	63
St. Lawrence	...	7	...	168	0.38	9.2	16.8	6.8	68
Washington	...	4	...	175	0.36	13.7	16.1	10.8	84
Wayne	...	4	...	173	0.59	10.2	15.5	8.7	71
			GABBRO.						
Essex	...	46	1	176	0.29	7.6	17.3	6.9	64
Warren	...	4	...	183	0.37	10.1	17.7	9.8	75

			GNEISS.					
Clinton ...	5		185	0.27	10.5	17.2	11.3	78
Dutchess ...	8	1	172	0.58	7.0	17.1	9.1	64
Essex ...	29	2	176	0.31	8.4	17.1	8.1	68
Franklin ...	8	...	178	0.50	6.2	16.1	7.8	59
Fulton ...	12	1	169	0.25	11.1	17.8	11.5	80
Hamilton ...	11	...	173	0.37	6.2	17.0	5.8	64
Jefferson ...	26	1	171	0.23	11.1	17.3	12.0	80
Lewis ...	6	...	167	0.27	9.6	17.9	10.6	75
Orange ...	7	...	179	0.38	7.1	17.1	6.4	62
Putnam ...	10	1	172	0.32	8.5	16.6	7.5	66
Saratoga ...	7	...	180	0.20	10.0	17.0	8.5	72
St. Lawrence ...	52	...	172	0.27	9.7	17.5	10.2	74
Warren ...	30	2	173	0.30	7.5	17.3	6.5	64
Washington ...	4	...	170	0.29	8.5	17.1	10.9	71
Westchester ...	37	2	171	0.39	8.3	16.9	7.8	67
			GRANITE.					
Essex ...	5	...	171	0.38	7.5	18.0	5.1	64
Franklin ...	6	...	165	0.31	8.7	17.9	9.4	71
Hamilton ...	5	...	165	0.36	9.9	18.1	9.0	75
Jefferson ...	23	1	166	0.23	12.1	18.4	10.1	83
Lewis ...	8	...	166	0.36	10.9	18.4	9.2	79
Oneida ...	6	...	166	0.13	10.2	18.9	8.2	77
St. Lawrence ...	30	...	165	0.25	9.9	18.3	8.1	74
Warren ...	5	...	165	0.45	7.9	17.9	7.7	67
			LIMESTONE.					
Albany ...	13	7	168	0.60	7.9	14.3	6.4	59
Cayuga ...	34	6	170	0.49	8.8	14 9	7.8	64
Clinton ...	14	2	170	0.28	8.2	14.1	5.3	58
Columbia ...	12	...	170	0.28	9.1	15 3	9.2	67
Erie ...	9	3	167	0.57	8.1	16.6	8.3	66
Fulton ...	6	1	168	0.21	7.7	15.5	6.5	60
Genesee ...	6	3	169	0.26	8.0	15.0	8.2	62
Greene ...	11	...	169	0.36	11.1	16.4	8.9	75
Herkimer ...	17	9	169	0.26	8.7	14.8	8.2	64

COUNTY.	Number of complete tests.	Number of partial tests [no core piece].	Weight lbs. per cubic foot.	Water absorbed. lbs. per cub. ft.	French co-efficient of abrasion.	Hardness.	Toughness.	Weighted value.
			LIMESTONE (Continued).					
Jefferson ...	105	44	169	0.28	7.6	15 1	6.4	59
Lewis ...	26	20	169	0.32	6.9	14.1	6.2	55
Madison ...	16	1	169	0.23	8.4	14.7	7.7	62
Monroe ...	4	...	168	0.27	8.1	14.1	7.4	60
Montgomery ...	12	2	160	0.24	8.5	15.3	8 0	64
Niagara ...	11	1	168	0.84	7.1	12.8	6.5	53
Oneida ...	31	19	169	0.29	7.8	13.8	6.6	58
Onondaga ...	25	1	170	0.38	8.9	15 7	8.4	67
Ontario ...	11	...	169	0.39	10.2	15.9	10.2	73
Otsego ...	7	2	169	0.32	8.1	14.1	6.3	59
Rensselaer ...	4	1	171	0.21	7.5	15.0	5.3	58
Saratoga ...	5	...	170	0.24	8.7	13.7	7.0	60
Schoharie ...	29	2	169	0.34	8.1	14 9	6.7	61
Seneca ...	7	3	169	0 21	9.4	15.3	7.9	67
Ulster ...	12	3	170	0.25	8.1	15.6	7.4	63
Warren ...	5	...	170	0.24	8.9	15.7	7.4	66
Washington ...	5	3	169	0.34	7.9	15.5	6.9	62
			MARBLE.					
Dutchess ...	4	...	178	0.30	7.3	14.2	6.0	56
			QUARTZITE.					
Columbia ...	16	...	168	0.28	16.5	18.3	17.1	103
Dutchess ...	8	2	166	0 36	13.5	18.8	11.8	90
Rensselaer ...	10	...	166	0.49	12.1	18.7	14.8	89
Washington ...	12	...	167	0.40	14.6	18.9	16.3	98
			SANDSTONE.					
Allegheny ...	8	...	156	2.10	8.4	13.4	9 1	61
Broome ...	11	...	165	1.29	7.8	12.9	10.5	60
Cayuga ...	4	1	167	1.16	7.8	12.1	10.5	58
Chenango ...	15	1	164	1.58	8.7	11.2	10,4	59
Clinton ...	14	...	163	0.71	11.7	18.5	11.0	83
Delaware ...	58	2	167	1.45	7.0	12.7	8.5	55

Erie	...	8	1	159	2.10	6.3	5.1	7.8	37
Franklin	...	5	...	157	1.06	9.7	17.9	7.1	72
Greene	...	6	...	169	0.62	8.6	14.5	8.1	63
Herkimer	...	4	...	160	2.50	10.9	16.4	10.7	76
Jefferson	...	8	...	156	1.46	8.3	16.2	6.3	64
Livingston	...	4	...	160	3.02	8.8	9.6	8.8	54
Madison	...	5	...	163	2.15	9.9	13.9	8.6	66
Niagara	...	7	...	158	1.78	9.0	16.4	8.2	68
Orleans	...	8	...	155	2.18	11.8	14.4	8.1	72
Otsego	...	21	1	162	1.75	8.4	11.9	9.6	59
Saratoga	...	5	...	163	0.36	10.7	18.0	8.7	77
Schoharie	...	6	3	165	1.21	9.4	15.2	11.7	70
Schuyler	...	4	...	162	2.14	8.1	11.6	10.6	58
Seneca	...	5	...	165	0.86	11.0	13.9	15.8	77
Steuben	...	22	3	157	2.70	8.3	9.3	10.0	54
St. Lawrence	...	16	...	159	0.79	10.0	17.8	7.2	73
Sullivan	...	30	4	164	1.26	6.5	14.9	8.2	58
Ulster	...	8	...	166	0.61	8.0	14.3	8.1	61
Syoming	...	7	...	159	2.54	6.0	5.1	7.9	36
				SANDY GRIT.					
Albany	...	5	...	167	0.75	7 5	13 2	7.2	56
Columbia	...	12	...	168	0.32	10.7	15.9	11.7	76
Dutchess	...	10	2	168	0.57	8.1	16 2	11.5	68
Greene	...	13	...	169	0.48	7.1	15.6	9.5	62
Montgomery	...	4	...	166	1.39	10.1	11.3	11.8	65
Rensselaer	...	10	...	169	0.44	9.1	15.9	9.4	60
Saratoga	...	5	...	168	0.99	11 8	15.2	11.9	78
Schenectady	...	4	...	165	1.10	9.2	14.6	9.5	66
Ulster	...	7	...	169	0.59	7.5	13.8	10.2	60
				SYENITE.					
Essex	...	7	...	184	0.52	7.7	17 1	6.7	64
Franklin	...	4	...	171	0.45	10.1	18.3	8.0	75
Herkimer	...	13	...	174	0.16	12.5	18.0	11.6	85
Jefferson	...	7	...	176	0.34	12.4	18.1	14.5	88
				TRAP.					
Rockland	...	12	...	183	0.39	13.2	17.6	1.64	91

APPENDIX 4.

BIBLIOGRAPHY.

As mentioned in the text of the paper the only significant works carried out, so far, in this country, in the study of road aggregates is that done, since 1924, at Government Test House at Alipore, supplemented by the petrological indentifications made by the successive curators of Geological Museum and Laboratory at Calcutta.

There is thus very little published indigenous literature, on this subject, available in this country and in writing this paper the author had to get considerable help from the following standard works, on the subject, for which he takes this opportunity of acknowledging his grateful thanks. Those who would like to make a detailed study of the subject can refer to these works with profit :—

1. Modern Road Constructions by Francis Wood.
2. Reinforced Concrete „ J. Singlaton-Green.
3. Principles of Highway Engineering. „ Wiley.
4 Road Aggregates „ Knight.
5. The Testing of Bituminous Mixture. „ „
6. Highway Engineers' Handbook. „ Harger & Bonney.

DISCUSSIONS ON PAPER No. 37.

Mr. R. L. Sondhi (Author) :—I have great pleasure in placing this Paper before the Roads Congress; and in doing so I expect to enlist support for my conclusions equally from the advocates of different road surface specifications; as whatever the mode of construction of a metalled road, water, tar, bitumen or concrete bound, the careful selection of the constituent aggregate is a cardinal necessity. It will perhaps be conceded by all the road experts gathered here that there is an economic use for every kind of stone.

Mr. L. B. Gilbert (United Provinces) :—Mr. Chairman and Gentlemen,—The merit of Mr. Sondhi's very interesting Paper, if I may say so, is in his showing that a number of properties must be taken into account when assessing the value of a road stone; the French co-efficient by itself is not sufficient indication. His references to the Barton index of quality and the American system of weighted values are very instructive, and it is unfortunate he did not go a step further and classify a series of road stone by both methods. Had this been done for the series in Appendix 2 or that in Appendix 3, the comparison would have been of considerable interest, and I am inclined to the view that a large measure of agreement would have been found between the two classifications. Mr. Sondhi, possibly, was not able to make the comparison because he was not able to obtain, in the time at his disposal, crushing values for either of the series referred to.

I have worked out the Barton index of quality and the weighted value of Bonowe granite and Fife Dolerite from the figures on page 152 of the paper, and have obtained the following results :—

Bonowe granite—index of quality 2.83
weighted value 118

Fife Dolerite—index of quality 2.1
weighted value 53.3

These two are, unfortunately, the only specimens for which sufficient data has been given, but the results tally with the classification in the last column of the table on page 152. Bonowe granite is undoubtedly "very good" and Fife Dolerite "poor" according to both English and American standards.

But there is one point on which I am not very clear, and that is the meaning of the term "abrasion figure" in the Barton formula. The co-efficient of hardness (h) is obtained from the formula:—

$$h=20-\frac{w}{3}$$

I have assumed that the Barton "abrasion figure" is represented in that formula by w, and it is on that assumption that I have worked out the indices of quality of Bonowe granite and Fife dolerite. I shall be very much obliged if Mr. Sondhi will let me know whether I have been correct in doing so.

I cannot understand the statement made by Mr. Sondhi in the paragraph on page 152 immediately preceding the table. As far as I can make out, the Barton formula gives satisfactory results which would, I believe, be supported by weighted values worked out by the American method.

The two formulæ referred to so far are designed for stone required for use in water-bound macadam. Similar formulæ are needed for stone to be painted with tar or bitumen, and still others for stone to be used in grout, premix or cement concrete. Here an important practical consideration arises. In water-bound macadam the very best stone available at reasonable cost should be used,

but in the more expensive forms of construction it is quite possible that an inferior, or at any rate, a stone possessing different characteristics, might be suitable. This might mean the use of a cheap local stone in preference to the importation of a more expensive one. The gap between the cost of good water-bound macadam and a more expensive form of construction might therefore be sufficiently reduced to permit of the more expensive form of construction being adopted.

It may appear, *prima facie*, that, with the establishment of a Test Track at Alipore, the evolution of formulæ for the classification of road stones is of only academic interest, but I do not believe that view will stand serious scrutiny. Both methods are required. For the work on the Test Track to be really helpful and of immediate and universal application, it is necessary for all relevant characteristics of road stone in the different provinces to be ascertained by laboratory methods and tabulated. Each stone would then receive an index number for each of the different types of work in which it might be used; *e.g.*, water-bound macadam, painted macadam, premix and cement concrete; the index number being obtained from the formula relating to that type of work. Tests on the track at Alipore might then, I would suggest, be carried out with a different range of what might be accepted as standard stones. The report on the test of a new method of construction or a new material would then state the limits within which the index figure of the stone should lie for satisfactory results.

Mr. W. L. Murrell (Bihar):—Mr. Chairman and Gentlemen.—At first sight it would appear difficult to find any flaw in such an excellent paper as that contributed by Mr. Sondhi, but the subject is one on which I am very keen and perhaps something I have to say may be helpful.

One criticism is that we are much more concerned with the wear of the road than with the wear of its aggregate. The two subjects are not necessarily identical, for the very best road aggregate in the world might corrugate under modern motor traffic unless certain considerations of the shapes and relative sizes of the pieces are given effect to.

In the Journal "Indian Engineering" published on the 7th October, 1933, I attempted to show how the corrugation of a road, under certain periodical wheel thrusts induced directly by the bouncing of motor vehicles, was a very similar phenomenon to the formation and augmentation of waves at sea under the action of wind.

This article assumed that, in a road corrugation, the crest of the corrugation was above the original level of the newly consolidated road, and that the trough was below such level.

In other words, the macadam had moved without actual disintegration, or it had "Flowed".

Let me now suddenly switch over to the "Handbook on the Code of Practice for Reinforced Concrete" recommended by the Building Research Board, England, and recently acknowledged by the Indian Railway Board when publishing their 1936 Standard Code.

The following are quotations from pages 12 and 14 of the Hand-book :—

(*i*) "In the production of good concrete the aim should be to obtain a sufficient degree of workability........ The degree of workability..........

is largely governed by the grading and shape of the aggregate particles."

(*ii*) "Shape of particles—Two similarly graded.........aggregates, one consisting of.........rounded and the other of angular or crushed particles, will exhibit markedly different degrees of workability......... The rounded aggregate ....will produce a more workable concrete than one composed of angular pieces."

(*iii*) "Proportions.........It can be taken as a rough guide that from 45 to 75 per cent of the total aggregate (fine and coarse) should pass through a sieve of aperture size equal to one-half of the maximum size of the coarse aggregate.

I now put it to all present that ordinary water-bound macadam with its mixture of large and small aggregates is not unlike a concrete. The similarity is increased if moorum, sand etc , have been used as a binder or a blinder. The similarity is further increased if the aggregates be damp or wet as in the monsoon, or in a badly drained road.

This view accepted, it is seen at once that the road engineer must avoid both rounded aggregate and graded aggregate, no matter how excellent the metal in all other respects.

Mr. Sondhi might, perhaps, have stressed a little more the question of shape.

Another criticism one might submit is that, among the tests to be applied to road aggregates, this paper does not mention size gradation. To me it seems an important omission. And I must express complete inability to agree with Mr. Sondhi when he says that "Screenings act as a filler and binder for water-bound macadam."

I would like to suggest, on the contrary, that the only binding force that should be relied on in water-bound macadam is the mechanical interlocking of pieces which are much the same in size. There should be no pieces of definitely smaller size, *i.e* , "screenings", to act as fulcrums or roller bearings by which one piece of aggregate can move relatively to another.

I would like to suggest further that, if any filler or binder is to be used, it should be a stabilised clay loam, sticky but non-shrinking. Even this filler should be avoided unless it is rolled in from the top as a blinder, and unless the surface is to be sealed.

It may be mentioned, as regards these screenings incorporated with the larger road aggregate, that they were once the cause of partial failure of one season's consolidation in a Sub-division of the Chota Nagpur Circle. Quartz metal had been used for many years, care being taken to collect only quartz free from crystal cleavage. The life of such consolidation was 4 to 6 years.

But in the instance referred to, failure by rapid corrugation took place within a year or two. The cause of this was neglect to prevent the collection of brittle quartz which became rounded under the consolidating roller, with the liberation of a large amount of small stuff as internal chips or "screenings".

It would appear that the importance of having ungraded aggregate for water-bound macadam is not sufficiently realized. I have even seen specifications for metal which insisted on the aggregate being graded. Doubtless this

grave mistake was due to the Engineer having, in some mysterious manner, mixed up the requirements for concrete work and for collection for water-bound macadam.

It was therefore not a moment too soon for the Technical Sub-Committee of the Indian Roads Congress to suggest standard specifications for road aggregates, vide page 176 of the Proceedings of the Second Meeting of the Indian Roads Congress.

As regards the prevention of gradation of road aggregate, I should perhaps explain how we in Chota Nagpur practise what we preach.

Metal collection is of 2 inch size, and stacks that contain small stuff passing a $1\frac{1}{2}$ inches mesh screen are rejected.

As all maintenance consolidation is done after picking up the old metal to an average depth of 3 inches, there is obviously the danger that small stuff may come in from the picked-up material.

Therefore, all picked-up material is immediatelv passed over a $1\frac{1}{2}$ inches mesh screen and only that which the screen refuses, is allowed to be spread back in the road bed.

It may be of interest to refer to further great economy attained by subsequent treatment of this stuff passing the $1\frac{1}{2}$ inches screen.

Before rain can get at it, this $1\frac{1}{2}$ inches stuff is passed over a $\frac{3}{4}$ inch, and then a $\frac{1}{4}$ inch square mesh screen.

The $1\frac{1}{2}$ inches—$\frac{3}{4}$ inch stuff is stacked for breaking to chips for seal coat work, thus reducing the cost of chips by about 60 per cent.

The $\frac{3}{4}$ inch—$\frac{1}{4}$ inch stuff is used partly to blind the metal surface after dry rolling is complete, and partly as chips for seal coat work.

NOTE.—Not more of this 3/4 inch—1/4 inch stuff should be used during wet rolling than is required to make the surface smooth-looking. If excess is used it will work into the metal and upset the mechanical interlocking

The $\frac{1}{4}$ inch—0 stuff is used sparingly for spreading on the metal during the final stages of wet rolling or "polishing".

Where sealing is not to be done, it is obvions that the $1\frac{1}{2}$ inches—$\frac{3}{4}$ inch and balance of the $\frac{3}{4}$ inch—$\frac{1}{4}$ inch salvaged material is available for the improvement of the flanks or berms in the manner suggested by Mr. Trevor Jones in his Paper No. 32 contributed to this Road Congress.

Perhaps I should mention that we have often tried consolidation with the new metal spread over a layer of mooram on the old road bed. But we have not yet succeeded in bringing this mooram blinder up to the surface during wet rolling, though the mooram was spread to the depth of nearly one inch in some cases. More mooram had to be added from the top, as a blinder, to complete the work.

The diversity of opinion among engineers as to how road aggregates should be consolidated is so great as to amuse our layman friends; and it is hoped that the Calcutta Test Track will, in due course, be able to help us in this respect.

Assuming again the role of critic, I would mention that Mr. Sondhi's Paper reminds me of a masterly treatment of this subject by A. L. Coulson, D.Sc. (Melb.), D.I.G., F.G.S., F.N.I., read at Dhanbad last November before

the Mining and Geological Institute of India, after Mr. Sondhi had submitted his paper.

The title of Dr. Coulson's paper is "Testing the Wear of Road Metals and Aggregates," and doubtless there will in time be a copy in our Congress Library.

My point is that the calling for tenders for the collection of road metal, the acceptance of such tenders, and the supervision of the actual collection under the contract, are all the duty of Sub-Divisional and Divisional Officers.

Also it is my experience in the Chota Nagpur Circle that the great majority of this executive establishment know only three kinds of road metal:—

Quartz—The mineral from dyke formations.

Bone—A whitish quartzite.

Trap—Any metal other than the above two !

This includes a great variety of igneous and metamorphosed rocks, but there is actually no basaltic metal used in the Circle.

The "co-efficient of hardness for hornblende schist", "the French co-efficient for quartzite" and such highly technical expressions, can mean absolutely nothing to this most important executive establishment as they cannot, in the first place, identify the rock concerned.

It therefore seems that the necessary first step is to furnish each Divisional and District Engineer with a small geological collection of his local rocks which have been "vetted" and named by real geologists.

Then indeed will the lamps of Mr. Sondhi and Dr. Coulson have something practical to shine upon !

As far back as 1915, as a fledgling graduate, I was responsible to the Country Roads Board of Victoria, Australia, for reports on microscopical sections and hand specimens of metal proposed to be used in big Government contracts.

Specimens for the formation of divisional geological collections are now accumulating at Circle Headquarters at Ranchi, and the Director of the Geological Survey of India has promised assistance in the identification etc., of the specimens.

May it therefore please be understood that these criticisms and remarks are not the outcome of lack of sympathy and understanding. They are the result of a desire to bridge the abysmal gap between the academic theory of road aggregates and the common engineering practice of road making and maintenance.

Mr. A. Nageswara Ayyar (Madras):— I congratulate the author of this paper Mr. Sondhi for the immense pains he has taken to collect the information regarding tests on road materials and for the lucid way he has presented them. I am sure the information he has furnished will be found very useful to Highway Engineers in India.

Regarding the Test House at Alipore, I recently visited it and the officer-in-charge was kind enough to take me round and explain the various tests that are being made on road materials. Unfortunately, I could not get a tabulated list

showing the materials tested so far and the results obtained under the various tests with regard to those materials. I am told that such a consolidated list is not being maintained. Unless full accounts of the tests made on road materials are published from time to time and made available to road engineers, the public will not derive the full benefit of the test house. I would therefore suggest that steps be taken to keep samples of all materials tested along with a card showing the quarry from which the materials were obtained and the test results in the headquarters museum of the province wherefrom the materials were quarried. Any amount of description cannot give us a clear idea of the stones as can be got by actual inspection of the sample. The museum is the best place for preserving these samples, as any engineer interested can have ready access to it. The results of tests so far made may also be collected and published for the information of the engineers.

Soling is a very important item on which I think this Congress should have a full discussion. A common specification for building macadam roads requires the provision of a hard and unyielding subgrade by packing stones six to nine inches thick and laying a coat of road metal over it. My personal experience is that wherever this type of soling was used, the metal coat was in a short time ground to powder and blown away leaving the soling exposed. This aspect was discussed in April 1936 in the Madras Local Board and Municipal Engineers' Association. The experience of almost every engineer present was that a boulder foundation was positively harmful to a road. There is a road with heavy traffic both in motor vehicles and bullock-carts leading from the Virudhunagar Railway Station to Aruppukottai in South Madras. This road runs in a black cotton embankment two to three feet high. Some stretches of this road had a soling of boulders and it was found that the metal in these stretches would wear out much quicker than in other places although the metal was of the same hard variety of granite throughout. On close observation the suspicion dawned on us that the rapid wearing of metal coat in some stretches was due to the soling For some time we feared that the removal of the boulders would be regarded as a retrograde step and against accepted specifications and tried other palliatives such as interposing a thin coat of gravel between the soling and metal coat. As these proved ineffective we removed the boulder soling and laid a moorum base and spread the metal coat over it. We had good results only after this was done.

We had constructed several miles of road in very bad soils like black cotton and we used to first lay a coat 6 to 9 inches thick of gravel, kankar, or moorum whichever is available close by and after consolidation spread a layer of hard road metal to a thickness of about 4 inches. This procedure invariably gave us satisfactory results. In some cases sand was tried but proved a failure. The kankar or gravel coat over a black cotton soil acts as follows :—

1. It presents an impervious mat preventing water from soaking through and wetting the black cotton.

2. It distributes the pressure as well as an ordinary soling does.

3. It presents a resilient subgrade.

4. It provides a good bed for the metal coat thereby preventing lateral movements and attrition of the stones forming the metal coat.

The adoption of this method of constructing roads has very considerably reduced initial costs and subsequent maintenance was economical. I think the specifications may be modified providing for a resilient carpet with gravel,

kankar, moorum or laterite instead of a hard soling with boulders.

Recently I had noted certain facts which give further information on the subject. In a portion of a heavy traffic road in Ramachandrapuram in East Godavari District, a three inch layer of hard trap metal was laid in November 1930 to a depth of 3 inches and width of 12 feet over an old *laterite* road in which the depth of *laterite* metal was about 5 inches. This road carries a traffic of over 700 bullock-carts and 40 buses per day corresponding to a traffic on the road of 1200 tons or three hundred tons per yard width per day. This road has been standing well with a little patchwork. In a similar stretch between Dowlaishweram and Kadiam over one mile was similarly treated in the same year and this too has been standing quite well so far. The traffic on this road is even heavier than what obtains in the previous case. On the other hand the same metal used on a granite metalled road does not stand for more than 3 years although the traffic in the latter case is only about half that obtaining on the two roads previously referred to. These observations indicate that good results can be obtained only by providing a resilient soling like gravel or kankar or laterite and laying a hard metal coat not exceeding 4 inches in thickness.

Methods of construction have therefore as much to do in the economical construction and maintenance of roads as quality of materials. If experiments on test tracks be made with materials laid in different ways now in vogue these will give valuable information. I do feel that although numerous experiments have been made on roads constructed with different forms of bituminous materials practically no tests or improvements have been made in the construction of macadam roads and these still continue to be built as per specifications laid over a hundred years ago by the famous inventor Macadam. For instance admixture of a little lime-stone screenings referred to in page 153 Section (b) of the author's paper have been found by me to give a considerably increased life to a macadam road and prevents the disintegration of stones in the hot weather. As it is admitted that for a long time to come macadam roads will continue as rural roads in this country it is highly necessary that improvements have to be effected in the methods of construction and maintenance of these. Information as to the maximum weights and speeds which these roads can safely stand would have to be found out and the loads and speeds limited to what they can stand for the benefit alike of motor traffic and bullock-cart traffic. In the Madras Presidency at any rate parallel roads on a large scale for the motor traffic will not I think be financially possible for a long time to come as the cry for more roads and bridges is incessant and all available funds have to be spent for providing them although even now we have over 25000 miles of metalled roads nearly equal to half the total milage of India.

Mr. E. F. G. Gilmore:—I am not going to say anything in detail about the results. I find the paper specially interesting as it voices a definite requirement that the Test House at Alipore should supply more information in connection with tests of road metals. That point has also been impressed upon me after examining the behaviour of the Jhansi stone in its various methods of use in the various places we have visited on these tours. As a result of this, I shall take early steps to introduce the impact and cementation tests. It has occurred to me, however, that information generally covering these details is provided by the remarks made by the Geological Survey incorporated in our reports, and in that connection I think it would be of interest if Col. Haig could tell us what remarks were made by the Geological Survey and included in the report on this stone, which, I understand we have tested.

Lt. Col. W. de H. Haig (United Provinces):—I am afraid I require notice.

Mr. E. F. G. Gilmore :—Well, these details are, I think, covered by their examination. Their remarks are, however, in the form of an expression of opinion, and I think it will be better if these characteristics are covered by actual test figures.

The author of the paper wants road tests on bajri or chips. That has not hitherto been possible with the available equipment at the Test House. Mr. Meares, however, drew my attention some time ago to a miniature track for such tests which has been developed in the United States, where they have become expert on tests and specifications of road materials and construction. This miniature track was reported on in the proceedings of the American Society for Testing Materials 1934, and we have discussed them and propose to put down such a miniature track in the new laboratories which I visualize will develop in the near future at the Test House. Meanwhile, the discussions which we had the other day in the Technical Sub-Committee in connection with the preliminary series of tests to be carried out on the main track cover that material.

I want to take this opportunity of pointing out that the putting into practice of the various proposals in this paper and those that have been made by members elsewhere as regards additional testing and research are going to cost money and are going to require staff. We at the Test House are a very small body. We have a staff of six gazetted officers together with a staff of 45 technical assistants, under whom are mistries, khalasies and so on, and we do work covering a wide range. If work in connection with the testing of materials for road construction is to be undertaken seriously, it will mean a considerable addition to that establishment. It requires consideration as to who is going to provide that.

Mr. K. G. Mitchell (Government of India):—In connexion with what Mr. Murrell has said that there was no way of relating the tests and petrological or geological description of stones to the actual stone used in practice, if some of you will send me during the course of the next few months two or three representative samples of the stone you use with its local name we will arrange at the time of the next Road Congress to exhibit a series of road stones giving the local name—the geological names, the French co-efficient and other information of that kind. If you think that is a good idea we shall arrange to have that done. In most cases we shall, I expect, be able to trace the tests already carried out but in one or two cases we may have to have fresh tests made.

A point on which Mr. Nageswara Ayyar wishes the opinion of the Congress is whether specifications which require rigid boulder soling can safely be departed from. He cannot expect the Congress to give a definite and sweeping opinion, out of hand but I imagine that everybody will agree that when you are using a brittle stone in the surface resilient soling is better than rigid

Mr. G. M. McKelvie (Central Provinces):—Mr. Chairman and Gentlemen,—I had not intended to speak on this paper but the observations of Mr. Murrell and Mr. Nageswara Ayyar came as a surprise to me and I thought I should say a few words about our experience in the Central Provinces. In the Central Provinces we do exactly the opposite to what both Mr Ayyar and Mr. Murrell generally recommend and our roads are very good. We have no corrugations as apparently exist on Bihar roads and no ruts or pot holes as in Madras. We use boulder soling—nearly everywhere where there is black cotton soil and

we include all sizes in our road metal except what we call choora *i.e.*, fines from 3/8 inch and downwards. Mr. Murrell said that he kept sizes from $2\frac{1}{2}$ inches to 2 inches and excluded the rest. This came as a surprise to me.

I think, as Mr. Mitchell has just said, it is all a question of the brittleness of the stone available for road metal. In the Central Provinces about 95 per cent of the roads are metalled with basalt ballast and the old specifications which were so thoroughly condemned by Mr. Ayyar are certainly suitable for our conditions. I think every province must have its own specifications. We are proud of our water-bound macadam roads in the Central Provinces and Berar and our existing specifications are generally satisfactory.

Colonel W. de H. Haig (United Provinces):—There are only two minor points that I want to mention, in regard to Mr. Sondhi's Paper. He refers to the Bitumen carrying capacity of stone. I understand that the Bitumen Companies in Europe and America do have a test for that and I think it would be extremely useful if Alipore could instal a machine for that purpose. I, personally feel very great doubt whether stone, which appears to be the best under the ordinary tests for water-bound metal, is necessarily the best when it is to be used in conjunction with either tar or Bitumen. Granite, which was mentioned just now, is what we have been using for a good many years in the central part of this Province and in and around Lucknow but I have very grave doubts whether it is really suitable for use with either Bitumen or tar. It is a fact that in the Agra and Meerut area where we have used several differant stones, including Delhi quartz, surface painting has, generally speaking, lasted much better than it has in the Cawnpore and Lucknow areas. You may say, "What about the traffic ?" On the average the tonnage of traffic in the Lucknow and Cawnpore divisions is greater than near Agra and Meerut but, at the same time, there are miles here which take no greater traffic than those in the west and which do not last as well. I rather feel that the capacity to carry Bitumen or tar may be one of the reasons why brick ballast has been successful: I have never had brick ballast tested by the ordinary Alipore test but I propose to send a sample for that purpose and some of this brick ballast, burned at the roadside on the Lucknow-Cawnpore Road is here to-day for you to see. I would not be surprised to find that although brick ballast proved inferior to granite under the ordinary test for road metal that it showed a greater affinity for Bitumen and Tar.

Another point mentioned in Mr. Sondhi's Paper was the question of chips and their liability to be crushed. We have on two or three occasions carried out rather a "Heath Robinson" test to ascertain the relative crushability. We took chips of several kinds—four or five—screened them so as to keep only those passing a 3/8 inch sieve but retained on a 1/4 inch sieve: in other words chips all of one size. We then took a measured quantity of these and spread them on a concrete floor and passed the roller over them a definite number of times. The remains were then swept up and sieved. The percentage which was found to pass the 1/4 inch sieve was regarded as having been crushed and it was found that there was a very great variation between the behaviour of different stones: I think the percentage crushed varied from about 18 to something like 45. I do not claim that the test is accurate but in the absence of anything better the result is perhaps useful.

Mr. C. D. N. Meares:—I did not intend to speak about bitumen carrying capacity but in view of Col. Haig's remarks it might interest you to know how we actually test this. The term "bitumen carrying capacity" is really a misnomer as it refers to the property peculiar to certain aggregates of carrying

more bitumen than others due to variations in surface texture. A better definition of the phenomenon mentioned by Mr. Sondhi is "Asphalt-water affinity".

Certain aggregates will unquestionably hold bitumen in the presence of water and others will not. The test developed by Nicholson gives an indication of this "Asphalt-water affinity" and is one which can easily be carried out by anybody, the only apparatus required being an ordinary wide mouthed jar.

The aggregate is first pulverized to the grading of a coarse sand, and great care must be exercised in doing so to see that the tools, etc., used are clean and free from rust as Iron Oxide will affect the result. Mix the pulverized material with a little bitumen liquefied with kerosene oil—usually 1 gallon kerosene to 2 gallons bitumen will give the desired consistency. Use as little liquefied bitumen as possible to get every particle coated.

Place about 50 grams of the mix in a jar, add some 100 cubic centimetres distilled water, and shake for 15 seconds. In some cases you will find most of the bitumen has stripped off the stone. This result seems to be brought about by two separate and distinct actions,—either by mechanical stripping due to the aggregate preferring a water coating to a bitumen coating or by actual emulsification of the bitumen by some chemical constituent in the aggregate. If stripping does not occur immediately, shaking should be continued with frequent pauses for inspection for 30 minutes. An aggregate is considered satisfactory if there is no stripping during this period.

I believe this property of certain aggregates to be of the utmost importance in asphalt road construction, and can quote several instances of failures which are probably directly attributable to poor asphalt-water affinity. The condition is easily corrected but work in this direction is still experimental and it is too early to speak yet. I think in the course of the Technical Sub-Committee's deliberations we should bring this matter up with a view to standardising a test such as the one described, but suggest that in the meanwhile any of you who are interested should try it out yourselves in order to collect as much data as possible.

Mr. R. L. Sondhi. (Authar) :—I am very grateful to the gentlemen who have very kindly offered criticisms. I will now try my best to reply to the points raised by them. Mr. Murrell says in earlier part of his criticisms that the subject with which my paper deals is one on which he is very keen and he feels that if ever he had anything useful to submit to any Road Congress it is now. He informs us that as far back as 1914 as a fledgling graduate, he was responsible to the County Road Board of Victoria, Australia, for reports on microscopical sections and handwritten specimens of metal proposed to be used in big Government contracts. All present will, therefore, agree on the point that if any one was proper person to read a paper on this subject it was Mr. Murrell. It may be perhaps that Mr. Murrell due to his thoughts working back to his fledgling stage deprived us from getting advantage of his ripe experience. He has been rightly selected, now, as a member of the Committee to obtain papers. Mr. Murrell says that we are much more concerned with the wear of the road than that of its aggregates. This reminds me of the very well-known mythical story about the individual members of the human body revolting against the body forgetting that they themselves constituted the body. The wear of a road surface will depend on that of the constituent parts and as explained in the paper aggregate is the important constituent and this paper is meant to concentrate our attention on that particular member of the surface body.

As regards the phenomenon of corrugation referred to by Mr. Murrell I do not think its consideration arises out of this paper, the object of which is stated in its opening paragraph.

My feeling is that corrugations would not occur in the water-bound surface with the ordinary motor traffic unless the consolidation was defective to start with. This would be the case if the blinding material, *i.e.*, screenings are introduced too early in the operation of consolidation. Another cause may be that the rolling is not done properly and crests and depressions caused by defective rolling are already there in the finished water-bound surface before traffic is allowed on it. A common mistake that occurs is that the roller is left, due to careless supervision, last thing in the evening, on wet consolidated portion. The surface not having dried may yield to the weight of the roller and a hollow is formed, similar phenomenon may be caused by local yielding strata in the subgrade with the result that pounding action is encouraged by the rythmic action of motor lorry traffic. I am afraid I have not had much opportunity to study or deal with the problem of corrugating in water-bound surfaces, which phenomenon appears to be a formidable problem that road engineers in Bihar, Orissa and Bombay Provinces have to face. In this connexion I can only suggest that we in the Punjab do our consolidation work perhaps so well that this trouble does not occur. Our specifications were, in a way, roughly outlined by Mr. Bashiram during the discussion on Mr. Dean's Paper, when he referred to the contrary practice he noticed in Delhi roads. By reference to the excellent paper on the subject of corrugations presented at our Inaugural Indian Roads Congress, 1934, by Mr. Cousens it will be seen that his conclusions after careful study of the surface so affected were that corrugations were not universal but only occurred in certain miles. He said that no definite cure had yet been discovered; but he suggested that possibly the use of sand as blindage, either by itself or mixed in other blindage, is the cause of corrugation. If sand is eliminated there is no corrugation. Worst corrugations occur when blindage is entirely sand and so on. These investigations relate to laterite metal roads. It will appear from the suggestions by that expert that corrugations are due to adoption of wrong specifications and are not the fault of aggregate as suggested by Mr. Murrell. The remedy, therefore, is as indicated in my paper in inventing suitable specifications for each class of work and standardising aggregates to suit each class of surface.

It will be further seen from my paper that I have attempted to recommend what qualities are desirable in aggregates employed for the different classes of surfaces and it is assumed that each specification will be laid down only in a standardised method which may have to be determined or altered by extensive experimental work on the Test track or under actual road-traffic. Thus my recommendations about the qualities of stone suitable for water-bound macadam apply to a road which will not 'flow' in the manner indicated by Mr. Murrell. Mr. Murrell first throws out a suggestion that water-bound macadam with its mixture of large and small aggregates is like concrete and says that I might have stressed a little more on the question of shape and gradation.

This requirement is indicated for water-bound surface at page 149 under Fracture Test and for Bituminous and Cement Concrete surfaces at pages 153 and 154. I have laid what I consider to be reasonable stress on these important requirements in my concluding remarks at pages 155 and 156 but I would agree with my critic that more stress could be laid with advantage on some of these requirements. Mr. Murrell also takes exception to my remarks that "screenings act as a filler and binder for water-bound macadam". I agree with him that mechanical interlocking is the sheet anchor of water-bound macadam and that screening should be introduced at a late stage of

consolidation. Another method adopted to suit certain varieties of aggregate is to work up the material from below. I have not yet had the opportunity of seeing the masterly paper of Mr. A. L. Coulson, referred to by Mr. Murrell, but will try to get a copy of it, as soon as I can and am indebted to Mr. Murrell for informing me about the existence of such a useful mine of information.

As regards Mr. Gilbert's remarks I intended to tabulate the "Indices of quality" and 'weighted values' but could not do so for the reasons correctly guessed by him.

It is interesting that he has kindly worked out these constants for two rocks for which the data was available in the table at page 152 of my paper. Mr. Gilbert is correct in assuming that "abrasion figure" in Barton's formula and "W" in the formula $L=20-\frac{W}{3}$ for co-efficient of hardness are identical things.

The statement made by me in the paragraph at page 152 immediately preceding the table is intended to mean that we should carefully tabulate information about the actual behaviour of stone available in different localities, and evolve local formulæ similar to those of Barton and others, after careful examination of such results.

I agree with Mr. Gilbert that further pursuits in the investigation of qualitias of stone may be expected to lead to economy by developing specifications which could also allow the use of inferior stone by clothing it with special binders.

As a result of experiments on stone aggregates at the Alipur Test House, I look forward with Mr. Gilbert to the classification of stones with index numbers indicating their relative utility for different classes of road surfaces. This will incidentally end with the fear of Mr. Murrell that his road subordinates will find it difficult to understand the existing technical terms indicating aggregate qualities. Moreover the research work in aggregates expected to be carried out at Alipur Test House will gradually disseminate the requisite theoretical knowledge amongst road engineers and as a result the trade will find specifications tightened up and inspections becoming more critical.

Mr. Nageshwara Ayyar stated that a list of tests carried out at Alipur was not available to him. This was published in the "Indian Roads" and is the basis of the present paper. I am afraid Mr. Ayyar has not perused his copies of the magazine. Mr. Ayyar's remarks about boulder soling foundations are interesting and deserve further investigation. It will be seen that I have not ventured to lay specifications; but have only indicated a line of action in this respect. Contrary to the experience of Mr. Murrell, Mr. Ayyar found early incorporation of screenings as suitable.

Mr. Gilmore has kindly agreed to supply more detailed information about stone tests, including impact and cementation tests from his Test House at Alipur. I believe in accepting thankfully that is given and then agitate to get more. He observes that routine tests on "Bajri" and grit have not yet been stadardised. As Bajri is a very costly item of road work in the Punjab, I hope, Mr. Gilmore will take early action in the matter, on the lines of the American practice referred to in my paper. I am glad that, in his remarks, Mr. Mitchell has helped me by answering most of the points raised by the speakers in the discussion of my paper. I hope, as a result of the investigations he proposes to

get carried out at the Roads Laboratory, the theory of the 'resilient' soling versus the "unyielding" one will be thoroughly gone into. The proposed examination of representative samples of stone from various localities is also sure to lead to useful conclusions.

Test for chips described by Col. Haig is an interesting one and may with some modifications be adopted at the Alipur Test House for determining comparative qualities of stone chips of different localities, to determine their suitability for various specifications.

Mr. Meares has described to you the usual Asphalt-water affinity test. I hope similar tests, will also be included by Mr. Gilmore in his standard tests for aggregates.

Finally I hope the co-ordinated efforts of road engineers all over India and the Road Laboratory at the Test House directed on road aggregates will lead to economies which may allow a longer milage of roads being constructed even with our existing resources.

Chairman:—I thank Mr. Sondhi for his paper which has led to a most interesting discussion. Before I leave the Chair I would like to propose a vote of thanks to Rai Bahadur Chhuttan Lal who has vacated the Chair after holding it for the whole year with credit to himself.

Col. G. E. Sopwith:—May I also say one word? I think I shall have the feeling of the whole meeting with me when I propose a vote of thanks to Mr. Mitchell who has worked more than anybody else for this Congress and he has to do this in addition to his other work. I think we all are deeply indebted to him.

Mr. K. G. Mitchell:—I thank you very much, but as a matter of fact I did very little and my friend Mr. Jagdish Prasad did the whole thing.

CHAIRMAN: Mr. W. R. Radice.

Chairman:—I call upon Rai Bahadur S. N. Bhaduri to present his Paper.

The following Paper was then taken as read:—

Paper No. 38.

SUBMERSIBLE BRIDGE ACROSS PARBATI RIVER AT MILE 231 AGRA-BOMBAY ROAD.

BY

Rai Bahadur S. N. Bhaduri, B.A., C.E., M.I.E., Chief Engineer Public Works Department, Gwalior Government.

The Parbati River crosses the Agra-Bombay Road at mile 231 from Agra. This river has a catchment area of 2,144 sq. miles at the site and has been observed during floods to rise over 48 feet above its lowest bed level. Before the

construction of the Parbati bridge the only means of crossing the river was provided by a causeway about 5 feet above the dry season water level of the river.

2. In the rainy season communication between the two banks of the river was maintained by a ferry boat. But during floods even this means of transport had to be abandoned till the water level came down to a depth of about 20 feet.

3. Owing to this break in the line of communications on an important trunk road, great inconvenience was felt by the public, and all kinds of traffic were held up for days together many times during the rainy season. The necessity of constructing a high-level submersible bridge in place of the existing Irish bridge was under the consideration of the Gwalior Government for some time past.

4. In June 1933 an estimate amounting to Rs. 3,75,000 was submitted to the Government of India for the construction of a reinforced cement concrete submersible bridge for provision of funds from the Road Fund Reserve. The Government of India having kindly consented in November 1933 to meet half the cost, tenders were invited.

5. In consultation with Mr. K. G. Mitchell, C.I.E., Consulting Engineer to the Government of India (Roads), the tender of Messrs. Indian Patent Stone Co. Ltd., (Managing Agents, Messrs Bird & Company of Calcutta) was accepted.

6. General details of the bridge are given below:—

(a) Span	103 feet
(b) Rise of arch from springing to intrados ...	21.25 feet
(c) Thickness of arch at crown	21 inches
(d) Thickness of arch at springing	36 inches
(e) Height of pier from lowest bed level to springing level	25.37 feet
(f) Thickness of pier at springing	8.5 feet
(g) Thickness of abutment pier at springing ...	18.5 feet
(h) Height of intrados at crown above lowest bed level	46.62 feet.
(i) Height of roadway above lowest bed level ...	50.30 feet.
(j) Overall length of bridge from wing to wing ...	988 feet.
(k) Overall width of bridge	21 feet.
(l) Clear roadway	18 feet.

7. Orders were passed by the Council of Regency Gwalior Government in February 1934, to proceed with the construction and actual work at site was started on the 15th March 1934 after the centre line of the bridge had been correctly laid out, at 245 ft. down-stream of the existing causeway.

8. With barely three months for the rains to set in, it appeared an uphill task to complete the foundations of all the six piers including an abutment pier before the monsoon. Even in the months of April and May, water-level in the river remained abnormally high being 4 feet above the mean bed level. Constant pumping from the pits of all the six piers had to be resorted to while making excavations. An air compressor with pneumatic demolishers had also to be installed to expedite excavation in rock. Disintegrated trap rock was found

down to an average depth of 5 feet below the lowest bed level. After this depth good hard rock was met with on which all the piers except No. 1 were founded.

In the case of pier No. 1 weathered rock was found on the surface. As this was removed disintegrated rock was met with. Borings disclosed this formation to a depth of 20 feet. It was, therefore, decided to found this pier on disintegrated rock, (locally called Bhisa), at a depth of 12.5 feet. A solid block of cement concrete 12.5 feet deep and of proportion 1 : 3 : 6 was laid to carry the pier masonry.

9. Besides filling the foundation of piers with concrete, side filling of foundation pits upto rock level was done in cement concrete to obviate any possibility of future scour by the river. Three concrete mixing machines were at work and it is to the credit of the Contractors that they completed the foundation work and brought up the masonry of the piers (which consisted of coursed rubble in cement mortar proportion 1: 4) to a height well above the October level of the river, before the rains set in. This enabled the Contractors to start work on the piers immediately after rains.

10. During the rainy season no work on the piers was possible but materials of construction were collected. It was not till the end of October 1934 that work could be resumed.

11. At this stage a proposal for raising the formation level of the bridge by six feet was approved by the Consulting Engineer to the Government of India (Roads), as it was seen that by doing so, the road level would be above the highest recorded flood level. It was also found that the amount required for this raising could be met out of the prospective saving of the total grant for the bridge.

12. Before deciding about the raising of the bridge it was ascertained that the increase in height of the piers would not in any way effect their stability and that no tension would be produced at any transverse section of the piers. Above the mean bed level of the river the piers including the abutment pier are made of 15" thick casing of coursed rubble masonry in cement mortar (1 : 4) with cement concrete hearting (proportion 1 : 3 : 6). The faces of piers are chisel dressed to present a smooth surface to flood waters.

13. Through the entire height of the piers, old rails of 42 lbs. weight per yard are placed vertically to serve as reinforcement. These are spaced 5½ feet apart in two rows 2 feet on either side of centre line. By means of cross rods these rails are anchored into rock to prevent slipping out.

14. For the abutments, hearting of solid masonry in cement mortar proportion 1 : 4 is used for half the height, above this to the springing level of arch cement concrete hearting (proportion 1 : 3 : 6) is used. It was observed that this proportioning gave satisfactory result for hearting.

15. The arches have been designed on the generally accepted elastic theory and are calculated to withstand a maximum loading of 12 British Standard Units including allowance for impact. Provision for the following effects has also been made:—

(1) Arch shortening.

(2) Temperature stresses (range of temperature being taken ± 30° F.)

(3) Buoyancy.

(4) Thrust due to velocity of approach of water in high floods (which is nearly 10 feet per second).

A feature of the design is that stresses due to dead load of the arches are eliminated by making the axis of the arch coincide with the line of pressure.

Detailed calculations for the Bridge done by Dr. Korni, Chief Enginere for the Contractors are given in the Appendix.

16. Longitudinal reinforcement of the arches consist of 3/4" diameter mild steel rounds placed 8" centre to centre both at top and bottom having 2" cover of concrete.

Cross reinforcement is by rounds 3/8" diameter placed 12" centre to centre, 3/8" diameter stirrups placed 2 feet apart join top and bottom reinforcements of the arch (*vide* plate No. 1).

17. To a passer-by, the timber centering for supporting the arches appeared a very complicated affair. In reality it was a very simple arrangement of scantlings of 'Hardwickia Binata' (called Anjan) obtained from the forests of the Central Provinces, Jubbulpore. Longitudinally they were placed 6'-$1\frac{1}{2}$" centre to centre and transversely 5 feet apart both resting on 10"×5" Salwood sleepers.

The verticals were effectively braced both horizontally and diagonally to form a very rigid frame, (*vide* photograph No. 1). By this arrangement the load on the centering was distributed to the made up soil on which the sleepers rested to a figure much less than $\frac{1}{2}$ a ton per square foot, allowable for such stuff. Wooden forms conforming to the curvature of the arch were carefully fixed to the tops of the verticals at required heights. Teak wood planks of an uniform width and thickness were laid on the curved forms and properly fitted and planed to have a smooth surface.

18. A skilled gang of about a dozen fitters, assisted by a couple of carpenters, erected one complete staging in three weeks. Before allowing reinforcement bars to be laid in position, several points on the profile of the intrados of the arch were checked and any errors in the levels of these were rectified.

19. By the middle of February 1935 the centering of the first arch was ready. As there were three sets of centerings on the work, concreting of arches proceeded without any interruption till the end of June 1935 when all the arches were completed.

20. It was found that with one concrete mixing machine of 10 cubic feet capacity it took nine days of eight-working hours each to complete one arch requiring 5,908 cubic feet of concrete.

Cement concrete for arch work consisted of 1 : 2 : 4 mix. Coarse aggregate which was broken from black trap stone was carefully graded from 3/4" to 1/4" size. Sand from the river bed was used after washing and screening through 1/8" mesh screen. The quantity of water was regulated so as to give concrete of the right consistency for reinforced concrete work. It varied from 5 gallons to $5\frac{3}{4}$ gallons per bag of $110\frac{1}{2}$ lbs. (nominally 112 lbs.) of cement.

21. During the whole time that the concreting of the arch was in progress, continuous supervision by a capable staff thoroughly acquainted with reinforced concrete work was maintained both by the department and by the Contractors, special care being given to punning and ramming. Everyday a compression test cylinder (6" diameter × 6" high) was cast from concrete actually going into the arch. After maturing, every third cylinder out of them was sent to the Government Test House, Alipur. Test results are given in Table No. 2 from which it will be seen that the average crushing strength of concrete varied from 4,100 lbs. per square inch to 3,192 lbs. per square inch against a minimum strength of 1800 lbs. per square inch required by specifications attached to the Contractors agreement.

22. The usual procedure during construction of arches was to do the skew backs first and then start arch work. First day's work was done on one side of the arch adjoining one of the skew backs. On the second day work was commenced on the other side, from the next skew back. On the third day concreting was done in continuation of first day's work. On the fourth day second day's work was continued. On the fifth day, the third day's work was carried forward. On the sixth day the strip done on the fourth day was continued. On the seventh day concreting was done at the crown on both sides of the centre line of the arch in order to prevent any tendency for the centering at the crown to bulge up. On the eighth and the ninth days the gaps remaining on each side of the crown strip were filled up and the arch completed.

The advantage of this arrangement was that it allowed nearly 36 hours to elapse before concrete was laid adjoining any strip previously done, allowing ample time for internal shrinkage to take place without causing additional stresses while setting.

The spandril walls are made of coursed rubble stone masonry in cement mortar 1 : 4. From the springing level to a height of nearly 14 feet thickness of these walls is 4 feet, after which the section gradually reduces in steps and at the top where coping is laid it is $1\frac{1}{2}$ feet. Inside the spandril walls, filling of haunches is done with lime concrete in which plums to the extent of 8 per cent were used. (*vide* plate No. 2).

23. An allowance of 1" was made in the centering at the crown for deflection likely to be caused by the load of concrete. A further allowance of 1" was made for plastic deformation, which in the case of concrete arches may take place after they have been subjected to loading. As a matter of fact, it was observed that on the removal of centerings, the actual sinkage at the crown of arches vareid from $\frac{1}{4}$" to $\frac{3}{8}$".

No plastic deflection has so far been noticed even after testing the bridge with a moving load of six steam road rollers of 12 tons weight each.

24. Transverse expansion joints have been provided in the spandril walls over each pier and at abutments; the allowance kept is 2" (*vide* plate No. 3). It was considered desirable to cover these expansion joints both on up-stream and down-stream faces of the spandril walls by an arrangement of an elbow shaped ashlar wall which would also prevent water in high floods from rushing freely through the opening of the joints as indicated in the plate referred to above. It gives an appearance of a rectangular ashlar pillaret rising from the top of cut water and screening the joint. As a suitable finish to this pillaret, a pedestal in cream coloured cement resting partly upon the pillaret and partly on the coping, built in a manner to preserve the expansion joint beneath, has been erected over each pillaret.

25. A sand cushion of 12" is provided over the crown of arches. Six inches thick lime concrete increased upto $8\frac{1}{2}$" at the centre of the road is laid on this sand cushion, allowing a camber of 1 in 50 to the road surface. The formation level of the bridge is level throughout. On top of the lime concrete a layer of clean sand about 2" thick is spread before laying cement concrete for the roadway. This has been done to allow a free sliding surface for the concrete roadway. The cement concrete for the road was laid in two layers—one of 4" thickness and the other of 2 inches.

26. To prevent cracks due to variation in temperature, reinforcement in the form of hexagonal hoops 22 inches across and made of $1\frac{1}{2}$"$\times$1/8" flats was laid on the 4" layer of cement concrete and then the surface finished by placing the top layer of 2". The road surface was subsequently treated with three coats of silicate of soda.

27. The coping is of reinforced cement concrete $1\frac{1}{2}$ feet wide by 9" high with a groove $4\frac{1}{2}$"$\times$$4\frac{1}{2}$", made centrally to take the collapsible railing (*vide* plate No. 2 showing cross section of spandril walls and roadway). It will be noticed that after every two lengths of railings a reinforced cement concrete wheelguard of the same height as the railing *viz.*, 3 feet has been placed. The object of building these is to indicate the roadway in case of its being submerged during extraordinarily high floods.

28. Railings of a collapsible type are provided (*vide* plate No. 4). By taking out special pins by means of a key, the railings fall into the groove provided in the coping and are therefore out of the way during floods. After the rains they can be re-erected without any difficulty or delay.

29. The bridge roadway was tested with a rolling load consisting of six steam road rollers of 12 tons weight each in the following way:—

(1) Three rollers were taken over the bridge from North to South with 10 feet space between.

(2) Again these were taken from South to North with a spacing of 5 feet.

(3) Then six rollers were taken over at intervals of 5 feet.

(4) Six rollers arranged two abreast with 5 foot spacing between each pair were then taken over the bridge.

(5) Three rollers from each side of an arch meeting at the crown of the arch.

(6) Finally six rollers were taken over the bridge at their maximum speed with a spacing of 5 feet.

(Test results are given in Table III).

30. To record the deflection produced on each arch the apparatus described below was improvised with the help of Mr. P. D. Tambat, Retired Agriculture Engineer, Gwalior Government:—

A piano wire with a free weight at the lower end was hung from the crown, the quarter point and the third point of each arch. The weight consisted of a piece of channel iron freely moving in another channel iron guide of a slightly larger size, (*vide* photo No. 4). To the weight a pencil arm was fixed in such a way that the pencil could mark the deflection on a drum carrying a piece of section paper. The drum was put in motion by a string controlled by a float placed in a cylinder full of water. This cylinder had three holes at the

bottom which were plugged by pieces of cork. These holes were calibrated in such a way as to give the drum one complete rotation in 1/2, 1, and 2 minutes. As soon as the steam rollers arrived near the end of an arch, the plug suitable for the particular test was removed and the drum began to rotate. The deflection due to the moving load on the bridge was marked by the pencil on the drum. Maximum bulging recorded was 1/16" at quarter point of the arch, with six rollers going two abreast at a distance of 5 feet between each pair and at a speed of 2½ miles per hour.

31. Roughly 1,35,000 cubic feet of cement concrete was done on this work including arch work. 82.5 tons of mild steel for reinforcement were used in the arches and nineteen tons of old rails were placed in piers. Eighteen tons of mild steel were used in collapsible railings. 1278.5 tons of Sun Brand cement were consumed on this work. Abstract estimate giving quantities of different items is shown in Table I. Total cost of bridge is Rs. 3,75,000/-.

32. The usual method of rating the cost of a bridge per foot run of length from abutment to abutment, or even per square foot of waterway or roadway does not give a sure basis of comparison of cost as between bridges of different types and sizes. Probably the fairest comparison of cost of bridges may be made by dividing the cost of the bridge by the cubical contents of the openings. By this method the rate per cubic foot of opening of the Parbati bridge works out to

$\frac{3{,}75{,}000}{7 \times 3915 \times 21}$	=	Rs. 0.65
The rate per foot run of bridge (length 988 feet)	=	Rs. 379.55
The rate per sq. ft. of opening (area 7 × 3915)	=	Rs. 13.68
The rate per sq. ft. of roadway (clear width 18 feet)	=	Rs. 21.08

33. The bridge was commenced on the 15th March 1934, and completed on the 5th March, 1936. It was tested with moving loads mentioned in paragraph 29 ante on the 8th and 9th April 1936, the results of which are given in Table III and are very satisfactory.

The bridge was opened to traffic on the 1st June, 1936.

TABLE I.

Parbati bridge at mile 231 of Agra-Bombay Road.
Abstract of works done and expenditure incurred.

S. No	Items	Unit	Quantity	Rate	Amount
1	Excavation of wet soil ...	%o cft.	21818.11	27/-	670/1/5
2	Excavation of hard rock ...	„	58160.10	110/-	6130/10/3
3	Side filling of trenches ...	„	87483.61	12/-	1019/12/10
4	Cement concrete 1: 3: 6 in foundation and side filling ...	% cft.	42638.71	61/-	27288/12/8
5	C. R. Stone masonry in cement 1 : 4 ...	„	6879.92	16/-	1181/8/8
6	Stone masonry in cement mortar 1: 4 above sill level ...	„	67939.5	48/-	32610/15/5
7	Supplying & fixing 42 lbs. old rails in masonry ...	rft.	3013.5	-/12/-	2260/2/-
8	Cement concrete 1 : 2 4 in caps of cut water ...	% cft.	779.92	85/-	661/3/8
9	Ruled cement pointing 1 · 3 mortar ...	% sft.	29518.78	6/8/-	1920/10/8
10	Chisel dressing to face-stone masonry ...	„	41327.97	12/8/-	5165/15/11
11	1 : 2½ : 5 R. C. concrete for skew back ...	cft	7071.91	2/4/-	15918/9/9
12	1 : 2 : 4 R. C. concrete for Arch work ...	„	41352.95	2/8/-	103382/6-
13	Plum lime concrete in haunches ...	% cft.	69991.08	20/-	13998/3/5
14	Sand and bajri filling for road cushion ...	„	7218	7/-	505/4/1
15	1 : 2 : 4 cement concrete for road surface ...	„	8828.55	100/-	8828/8/9
16	R. C. C. coping ...	cft.	1901.65	2/8/-	4754/1/11
17	Fixing holding down bolts for collapsible railing	No.	636	1/4/-	795/-
18	Excavation of dry soil ...	%o cft	204169.72	12/-	2450/-/6
19	Lime concrete in foundation of wings with 40 per cent mortar ...	% cft.	6119.25	22/-	1316/3/9
20	Stone masonry in lime mortar above sill level ...	„	84147.39	37/-	31131/8/6
21	Collapsible railings ...	rft.			7824/-
22	Approach road ...	L. S.			9624/-
23	Land compensation ...				174/12/8
24	Pitching for side banks of river and protective earth work ..				4033/11/7
25	Excavation of soft rock ...	%°cft.	1265	70/-	88/8/9
26	Cement concrete 1 · 3 · 6 in hearting of piers .	% cft.	21457.92	66/-	14162/3/6
27	Cement concrete 1 : 4 : 8 in hearting of abutments	% cft	8013.94	55/-	1124/2/8
28	Cement concrete 1 : 2½ : 5 for backing of skew back ...		1790.46	72/-	1289/2/-
29	Cement concrete 1: 2: 4: with 3/4" stone chips to fill grooves of expansion joints .	„	805.68	91/-	737/8/5
30	Stone masonry in cement mortar 1: 6 in hearting of abutments ...	„	8405.58	41/-	3446/4/7
31	Lime concrete below roadway of cement concrete with 33 p. c. mortar	„	9003.64	20/-	1800/11/7
32	Ashlar stone masonry for protecting expansion joints ..	„	1201.73	1/8/-	1802/9/6
33	1: 2: 4 R. C C. corbelling under ashlar pillars at expansion joints of abutment ..	cft.	35	2/8/-	87/8/-
34	Making grooves in masonry and fixing copper sheets in expansion Joints ...	„ rft.	433.68	-/9/-	243/15/-
35	Fixing copper sheets on horizontal expansion Joints ...	„	171	-/1/-	10/11/-

TABLE I—*(Continued).*

S. No.	Items	Unit	Quantity	Rate	Amount
36	Copper sheets 1/16" thick for expansion joints ...	cwt.	30		1835/14/6
37	Extra sand filling for cushion ...	% cft.	13075.10	3/8/-	457/10/-
38	Sand filling between wings ...	"	17448.22	3/8/-	610/11/-
39	1 : 2 : 4 R. C. C. wheel guards ...	cft.	264	2/8/-	660/-
40	Pedestal in white water proof cement ...	No.	22	about 40/- each	853/14/3
41	Laying the road surface in two layers with hoop iron reinforcement for prevention of temperature cracks ...		8828.55	-/2/-	1103/9/1
42	Hoop iron for road reinforcement ...	cwt	65		667/10/3
43	Bending and laying hoop iron reinforcement ...	"	60	1/4/-	75/-
44	Supplying Silicate of soda ...	cwt.	10	12/-	120/-
45	Rendering with Silicate of Soda three coats ...	% cft.	25677.59	2/-	513/8/9
46	Filling mexphalt and sand in expansion joints of road, extra length ...	rft.	1759.5	-/8/-	879/12/-
47	Extra for staging ...	span	7	300/-	2100/-
48	Extra lift of masonry and lime concrete ...	% cft.	304406	1/-	3044/-
49	Extra lift for arch and skew back concrete ...	"	50360	1/8/-	755/6/4
50	Temporary staff quarters ...				10200/7/11
51	Testing of the bridge ...		...		2812/-
52	Work establishment ...	@ 4%	...		6368/15/3
53	Contingencies ...	@ 5%			6616/-
54	Supervision charges ...	@ 10%			25701/10/1
					3,80,418/10/10
	Deduct 4 per cent. on cement concrete items for use of local sand instead of Sindh River sand as per agreement with Contractors ...				5,418/10/10
	TOTAL ...			Rs.	3,75,000/-/-

TABLE II.

Statement of results of compression test of cylinders of concrete actually going into arches of Parbati bridge at mile 231, Agra-Bombay Road.

S. No.	Arch No.	Result of compression test (average of three cylinders tested for each arch).		Date of construction of Arch.	Remarks.
		Tons per sq. inch.	Lbs. per sq. inch.		
1	1	1.87	4100	14-2-35 to 22-2-35	
2	2	1.80	4030	28-2-35 to 9-3-35	
3	3	1.703	3815	14-3-35 to 18-3-35	
4	4	1.57	3524.26	9-4-35 to 17-4-35	During the hot months of April and May the cylinders appear to have developed comparatively less strength.
5	5	1.425	3192	23-4-35 to 1-5-35	
6	6	1.47	3292.80	12-5-35 to 20-5-35	
7	7	1.51	3382.40	26-5-35 to 2-6-35	

N.B.—It will be noticed that test results of 1, 2 and 3 arches which were done in February and March are comparatively higher than those of arches 4, 5, 6 and 7 which were done in hot months. This seems to be due to the higher atmospheric temperature, otherwise there was no difference in the grading, mixing, laying, and supervision.

The staff employed from the beginning to the end of construction of arches was the same.

TABLE III.

Statement showing the results of testing Parbati bridge on mile 231, Agra-Bombay Road, P.W.D., Gwalior Government.

Arch number	Test on 8th April 1936									Test on 9th April 1936.									Remarks.
	Three rollers 10′ apart			Three rollers 5′ apart			Six rollers 5′ apart			Six rollers arranged 2 abreast 5 feet apart			Six rollers, three from each side			Six rollers at maximum speed 5 ft. apart.			
	Crown	1/4 point	1/3 point	Crown	1/4 point	1/3 point	Crown	1/4 point	1/3 point	Crown	1/4 point	1/3 point	Crown	1/4 point	1/3 point	Crown	1/4 point	1/3 point	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Arch No 1	+1/30	...	...	+1/30"	...	...	+1/20"	...	...	+1/20"	—1/16"	—1/40"	...	...	...	+1/30"	...	—1/40"	—denotes downward deflection. +denotes bulging up.
" " 2	+1/30"	...	...	+1/30"	...	...	+1/30"	...	...	...	...	...	...	...	...	...	...	...	
" " 3	...	+1/20"	...	...	+1/20"	...	...	...	...	...	...	...	...	...	...	...	...	...	
" " 4	...	...	...	...	...	...	+1/30"	—1/20"	...	+1/60"	—1/20	1/10"	—1/10"	—1/30"	...	+1/40"	—1/20"	...	
" " 5	...	—1/20"	...	...	—1/30"	...	...	—1/20"	...	...	...	...	...	...	...	...	—1/20"	...	
" " 6	...	—1/30"	...	...	...	...	...	—1/20"	...	...	...	...	...	...	...	...	—1/20"	...	
" " 7	+1/40"	...	...	+1/40"	...	...	+1/30"	...	...	...	...	...	...	...	...	+1/20"	...	...	

APPENDIX

Calculations of Parbati Bridge.

BY

Dr. M. A. Korni.

The Bridge will be of 104 feet span,—width between faces—21 feet.

The elastic arch is fixed under the assumption that the piers and abutments will have no settlement.

The method of calculation is according to the theory of Prof. Marsh.

The equations of Elastic properties of the arch are only for the Bending Moments, which are essential in this case.

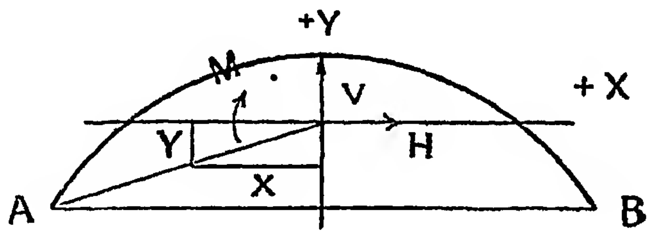
It has been assumed that the statical undeterminate reaction in A is removed and replaced by a stress AV which is a component of the forces causing a moment "M" and Horizontal force "H" and vertical force "V". This renders us a statically determinate system with a fixity in B.

∴ the equation will be:—

(1) $O=\int\frac{Mx}{EJ}ds.y+a.t.l$

(2) $O=\int\frac{Mx}{EJ}ds.\ x$

(3) $O=\int\frac{Mx}{EJ}ds$



Mx means B.M. at any point x.

There is $Mx=Mo+M-Hy-Vx$.

The point O has been chosen such that :—

$$\int\frac{x\,ds}{J}=O$$

$$\int\frac{y ds}{J}=O$$

and $$\int\frac{x.y.ds}{J}=O$$

Assuming $\frac{ds}{J}=dw$, the magnitude of H, M and V, can be found from the equations:—

$$H=\frac{\Sigma\,Mo y.\omega.+E.a.t.l}{\Sigma\,J^2.\,\omega}$$

$$M=\frac{\Sigma\,Mo\omega}{\Sigma\,\omega}$$

$$V=\frac{\Sigma\,Mo.x.\omega.}{\Sigma\,x^2.\,w}$$

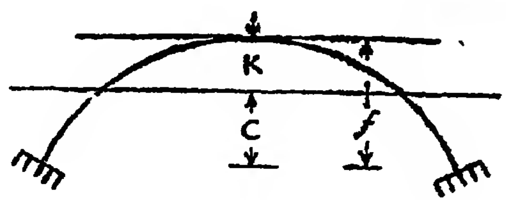
In our calculation we have made the arch of Equal lengths S. Therefore the $\int$ sign has been replaced by Σ and thus $dw=w$

$$\therefore\quad w=\frac{S}{J}$$

Sect.	Δ^s	b	h	$J=\frac{bh^3}{12}$	T′	$w=\frac{\Delta^s}{J}$	wy'	$f-y'$	$w(f-y')$
I	88″	12″	33″	$\frac{12\times33^3}{12}=36000$	36″	$\frac{88}{36000}=0.00244$	$.00244\times36=0.088$	$264-36=228''$	$.00244\times228=.556$
II	88″	12″	32″	$\frac{12\times32^3}{12}=32800$	103.2″	$\frac{88}{32800}=0.00268$	$.00268\times103.2=0.276$	$264-103.2=160.8''$	$.00268\times160.8=0.431$
III	88″	12″	31″	$\frac{12\times31^3}{12}=29800$	157.2″	$\frac{88}{29800}=0.00295$	$.00295\times157\ 2=0.465$	$264-157.2=106.8''$	$.00295\times106.8=0.314$
IV	88″	12″	28″	$\frac{12\times28^3}{12}=21900$	198″	$\frac{88}{21900}=0.004$	$.004\times198=0.794$	$264-198=66''$	$.004\times66=0.264$
V	88″	12″	27″	$\frac{12\times27^3}{12}=19700$	225″	$\frac{88}{19700}=0.00446$	$.00446\times225=1.001$	$264-225=39''$	$.00446\times39=0.174$
VI	88″	12″	25″	$\frac{2\times25^3}{12}=15650$	244.8″	$\frac{88}{15650}=0.00562$	$.00562\times244.8=1.375$	$264-244.8=19.2''$	$.00562\times19.2=0.108$
VII	88″	12″	24″	$\frac{12\times24^3}{12}=13800$	258″	$\frac{88}{13800}=0.00637$	$.00637\times258=1.645$	$264-258=6''$	$.00637\times6=.0382$
VIII	88″	12″	21″	$\frac{12\times21^3}{12}=9270$	262.8″	$\frac{88}{9270}=0.0095$	$.0095\times262.8=2.495$	$264-262.8''=1.2''$	$.0095\times1.2=0.0114$
						0.03802	8.139		1.8966

$$C=\frac{\int wy'}{\int w}=\frac{2\times8.139}{2\times0.038}=214''.$$

$y=y'-c$	wy	wy^2	x	wx	wx^2	wyx	$\frac{\Delta^6}{F}=\frac{\Delta^6}{bh}$
36−214 =−178	−.00244×178 =−0.435	−0.435×−178 =77.0	595.8	.00244×595.8 =1.45	1.45×595.8 =865	−.435×595.8 =−259	88/396=.222
103.2−214 =−110.8	−.00268×110.8 =−0.297	−0.297× −110.8=32.8	532.8	.00268×532.8 =1.425	1.425×532.8 =760	−.297×532.8 =−158	88/384=.228
157.2−214 =−56.8	−.00295× 56.8=−0.168	−0.168×−56.8 =9.54	462.6	.00295×462.6 =1.365	1.365×462.6 =632	−.168×462.6 =−77.8	88/372=0.236
198−214 =−16	−.004×16 =−0.064	−0.064×−16 =1.02	385.2	.004×385.2 =1.54	1.54×385.2 =594	−.064×385.2 =−24.6	88/336=0.261
225−214 =11	.00446×11 =0.0491	.0491×11 =.540	307.2	.00446×307.2 =1.37	1.37×307.2 =421	.0491×307.2 =15.1	88/324=0.270
244.8−214 =30.8	.00562×30.8 =0.173	0.173×30.8 =5.33	219.6	.00562×219.6 =1.23	1.23×219.6 =270	.173×219.6 =37.9	88/300=0.292
258−214 =44	.00637×44 =0.280	.280×44 =12.2	133.2	.00637×133.2 =0.85	0.85×133.2 =113	0 280×133.2 =37.4	88/288=0.304
262.8−214 =48.8	.0095×48.8 =0.462	.462×48.8 =22.4	43.8	.0095×43.8 =0.416	0.416×43.8 =18.25	.462×43.8 =20.2	88/252=0.348
	+0.964−0.964	160.83		9.646	3673.25	−519.4 +110.6 −408.8	2.161



$$K=\frac{\int w(f-y')}{\int w}=\frac{2\times 1.8966}{2\times 0.03802}=50$$

Rise $f=c+k=214+50=264''$

P=1 in.	wy	x	a	$\sum\limits_{a}^{-l/2} wy(a-x)$	$\sum\limits_{-l/2}^{+l/2} wy^2+\frac{\Delta^2}{F}$	P=1 in.	H
2′	−0.435	595.8	566	−13.0	325.98	2	0.04
4′	−0.297	532.8	500	−51.35	325 98	4	0.158
6′	−0.168	462.6	424	−113.9	325.98	6	0.354
8′	−0.064	385.2	346	−186.5	325.98	8	0.577
10′	0.0491	301.2	262	−265.0	325.98	10	0.819
12′	0.173	219.6	176	−335.6	325.98	12	1.04
14′	0.280	133.2	88	−389.35	325.98	14	1.21
C	0.462	43.8	0	−408.8	325.98	C	1.26
B				0.00	325.98	A	0.00

$$H=\frac{\sum\limits_{a}^{-l/2} wy(a-x)}{\sum\limits_{-l/2}^{+l/2} wy^2+\frac{\Delta^2}{F}}$$

P=1 in	$\sum_{a}^{-l'_2} w(a-x)$	$\sum_{-l'_2}^{+l'_2} w$	M	P=1 in	$\sum_{a}^{-l/_2} w(a-x)$	M
B	0.00	0.076	0.00	A	47.573	626
2′	.073	.076	0 96	2	43.093	568
4′	322	.076	4.25	4	38.361	505
6′	.822	076	10.8	6	33.075	436
8′	1.612	.076	21.3	8	27.913	369
10′	2.842	.076	37.5	10	22.738	300
12′	4.495	.076	59.2	12	17.863	235
14′	6.729	.076	88.8	14	13.415	177
C	9.646	076	127	C	9.646	127

$$M=\frac{\sum_{a}^{-l/_2} w(a-x)}{\sum_{-l/_2}^{+l/_2} w}$$

P=1 in	$\sum_{a}^{-l/2} wx(a-x)$	$\sum_{-l/2}^{+l/2} wx^2$	V	P=1 in	V
B	0.00	7346.5	0.00	A	1.00
2′	43.2	7346.5	.0059	2	0.9941
4′	185.8	7346.5	.0253	4	0 9747
6′	457.7	7346.5	.0624	6	0.9376
8′	847.5	7346.5	0.115	8	0.885
10′	1398.0	7346.5	0.191	10	0.809
12′	2066.7	7346.5	0.282	12	0.718
14′	2837.5	7346.5	0.386	14	0.614
C	3673.25	7346.5	0.500	C	0.500

$$V = \frac{\sum_{a}^{-l/2} wx(a-x)}{\sum_{-l/2}^{+l/2} wx^2}$$

CENTRE SECTION.

P=1 in.	Mos	M	−H.y	Ms	P=1 in	Mos	M	−Hy	Ms
B	0.0	0.0	0.0×50 =0 0	0.0	A	−626	626	−0.0	0.0
2′	0.0	.96	.04×50 =−2.0	−1.04	2	−566	566.96	−2.0	−1.04
4′	0.0	4.25	0.158×50 =−7.9	−3.65	4	−500	504.25	−7.9	−3.65
6′	0.0	10.8	0 354×50 =−17 7	−6.9	6	−424	434.8	−17.7	−6.9
8′	0.0	21.3	0.577×50 =−28.9	−7.6	8	−346	367.3	−28.9	−7.6
10′	0.0	37.5	0.819×50 =−40 8	−3.3	10	−262	299.5	−40.8	−3.3
12′	0.0	59.2	1.04×50 =−52	+7.2	12	−176	235.2	−52	7.2
14′	0.0	88.8	1.21×50 =−60 6	28.2	14	−88	176.8	−60.6	28.2
C	0.0	127	1.26×50 =−63.0	64	C	0.0	127	−63	64

$$Ms = Mos + M - Hy - Vx$$

$x = 0.0$
$y = 50''$

P=1 in	M_{os}	M	$-Hy$	$-Vx$	M_s	P=1 in	M_{os}	M	$-Hy$	$-Vx$	M_s
B	0.00	0.00	0.00×2 =0.00	0.00×346 =−0.00	0.00	A	−280	626	0.0	1.00×346 =−346	0.0
2′	0.00	0.96	.04×2 =.08	.0059×346 =−2.06	−1.18	2	−220	566.96	−0.08	.9941×346 =−344	2.88
4′	0.00	4.25	.158×2 =−.316	0.253×346 =−8.75	−4.816	4	−154	504.25	−0.316	.9747×346 =−336	13.934
6′	0.00	10.8	.354×2 =−.708	.0624×346 =−21.6	−11.508	6	−78	434.8	−0.708	.9376×346 =−324	32.092
8′	0.00	21.3	.577×2 =−1.154	.115×346 =−39.8	−19.654	8	0.0	367.3	−1.154	.885×346 =−306	60.146
10′	0.00	37.5	.819×2 =−1.638	.191×346 =−66.1	−30.238	10	0.0	299.5	−1.638	.809×346 =−279	18.862
12′	0.00	59.2	1.04×2 =−2 08	.282×346 =−97.6	−40.48	12	0.0	235.2	−2.08	.718×346 =−248	−14.88
14′	0.00	88.8	1 21×2 =−2.42	.386×346 =−133	−46.62	14	0.0	176.8	−2.42	.614×346 =−212	−37.62
C	0.00	127	1 26×2 =−2.52	.5×346 =−173	−48.52	C	0.0	127	−2.52	.5×346 =−173	−48.52

$$M_s = M_{os} + M - H.y_s - Vx^s$$

$$x_s = +346$$

$$y_s = +2''$$

SPRINGING SECTION.

P=1 in	Mos	M	−Hy	−Vx	Ms	P=1 in	Mos	M	−Hy	−Vx	Ms
B	0.0	0.0	0.0×214 =0.0	0.0×626 =0.0	0.0	A	0.0	626	0 0	1.0×626 =−626	0.0
2′	0.0	0.96	.04×214 =8.56	.0059×626 =3.7	5.82	2	0.0	566.96	8 56	.9941×626 =−620	−44.48
4′	0.0	4.25	.158×214 =34	.0253×626 =−15.8	22.45	4	0.0	504 25	34	.9747×626 =−608.25	−70 0
6′	0.0	10.8	.354×214 =76	.0624×626 =−39	47.8	6	0.0	434.8	76	9376×626 =−584.8	−74
8′	0.0	21.3	.577×214 =124	.115×626 =−72	73.3	8	0.0	367.3	124	.885×626 =−553.3	−62
10′	0.0	37.5	.819×214 =175	.191×626 =−119	93.5	10	0.0	299.5	175	.809×626 =−505.5	−31
12′	0.0	59.2	1.04×214 =223	.282×626 =−176	106.2	12	0.0	235.2	223	.718×626 =−450.2	8
14′	0.0	88.8	1.21×214 =260	.386×626 =−241	107.8	14	0.0	176.8	260	.614×626 =−383.8	53
C	0.0	127	1.26×214 =270	.5×626 =−313	84	C	0.0	127	270	.5×626 =−313	84

$$M_A = Mo_A + M - H.y_A - Vx_A.$$

$$x_A = 626$$

$$y_A = -214$$

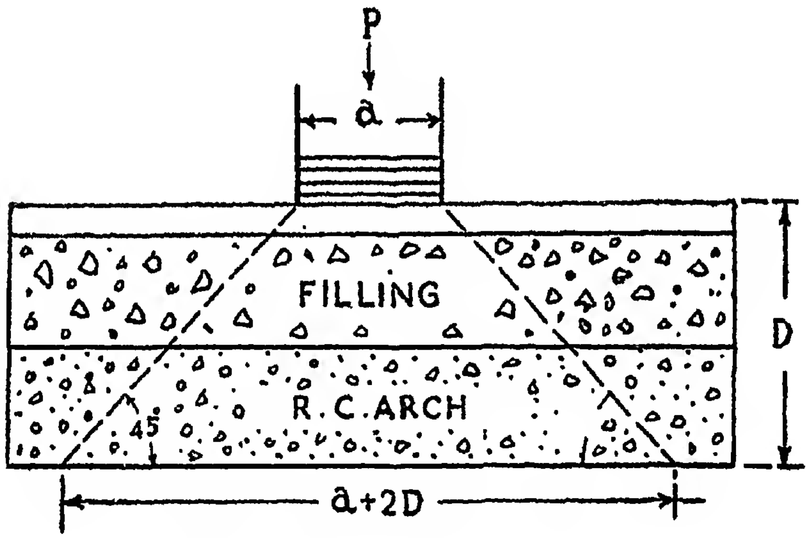
DISPERSION OF LOADING.

For spandril filled arches which comprise a curved slab it is customary to consider a longitudinal strip of slab one foot wide.

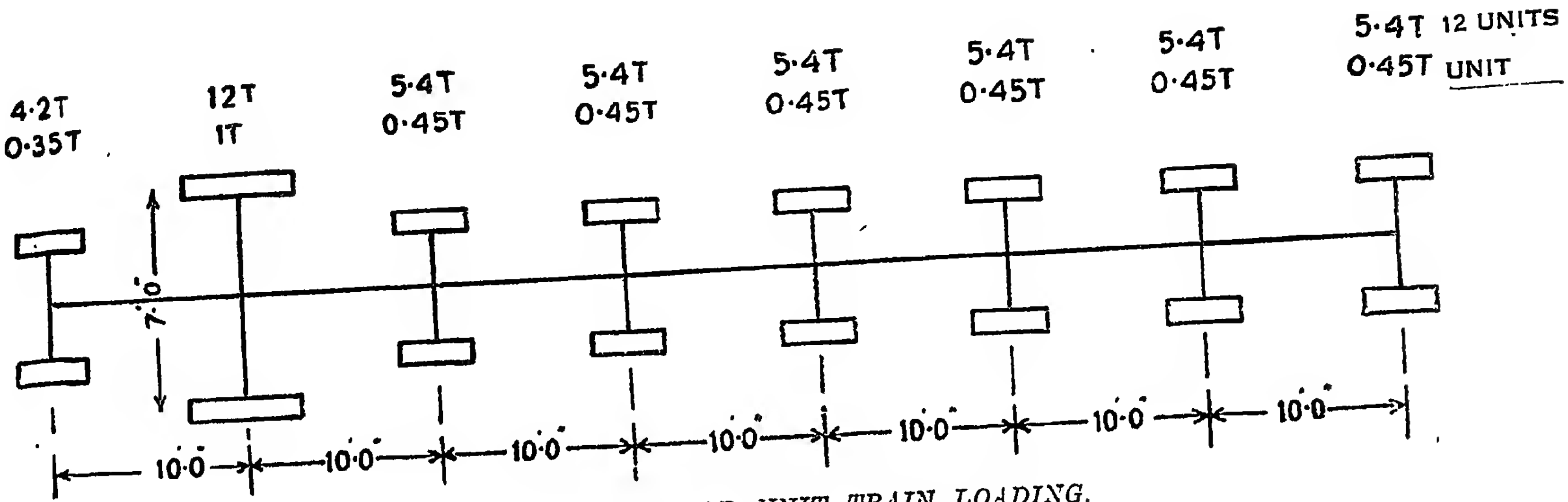
In this type of Bridge the concentrated wheel loads will spread through the filling and where the minimum depth is 4′ – 0″ from the point of contact to the Intrados of the Arch Slab, the standard train of wheel loads may be considered to be uniformly applied.

In flat arches having less than the above stated minimum depth the proportion of each point load coming upon a longitudinal strip of arch amounts to $\frac{P}{a+2D}$.

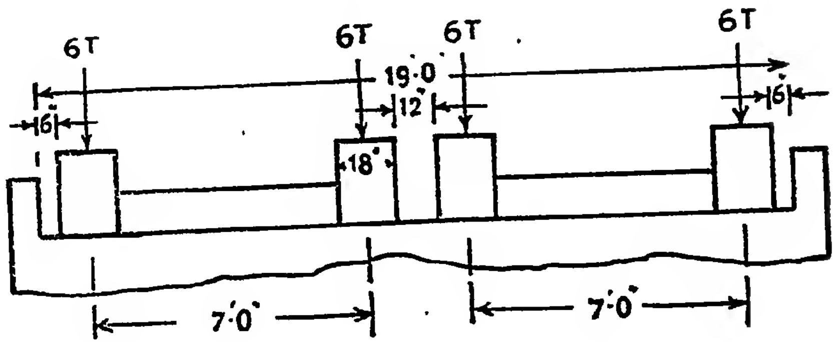
The point loads are applied to the influence line diagram in the usual manner.

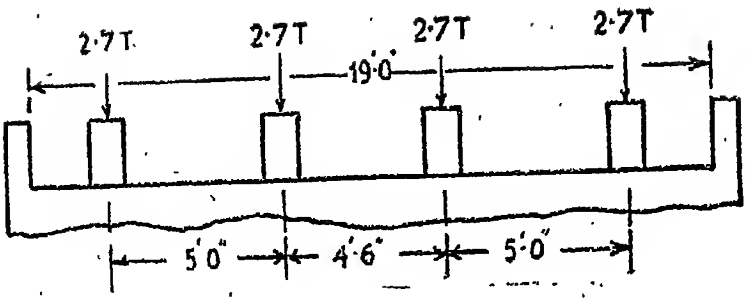


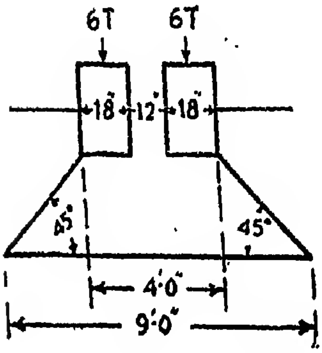
DISPERSION OF WHEEL LOADS.



B. E. STANDARD UNIT TRAIN LOADING.

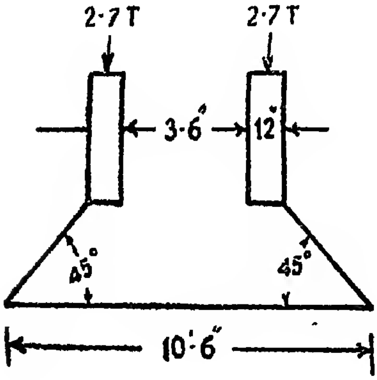






Reaction at Crown for 12 ton Load

$=\frac{12}{9}=1.33$ tons/ft.

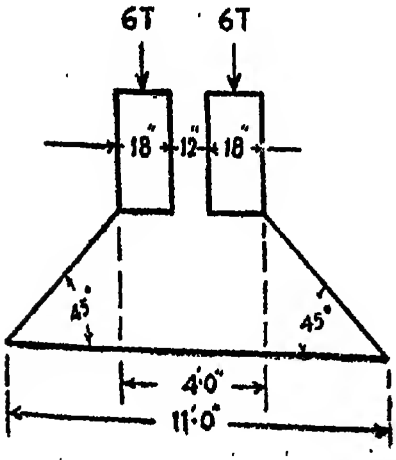


Reaction at Crown for 5.4T Load

$=\frac{5.4}{10.5}=0.515$ tons/ft.

Reaction at Crown for 4.2T Load

$=\frac{4.2}{10.5}=0.40$ tons/ft.

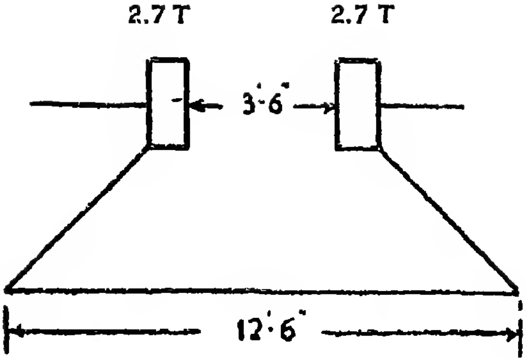


Reaction at 10′ distance from the Crown for 12T Load

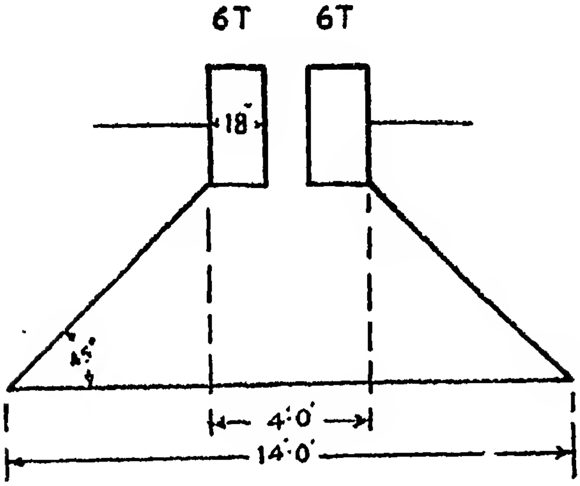
$=\frac{12}{11}=1.09$ tons/ft.

Reaction at 10′ distance from the Crown (for 5.4 Ton Load)

$=\frac{5.4}{12.5}=0.432$ tons/ft.

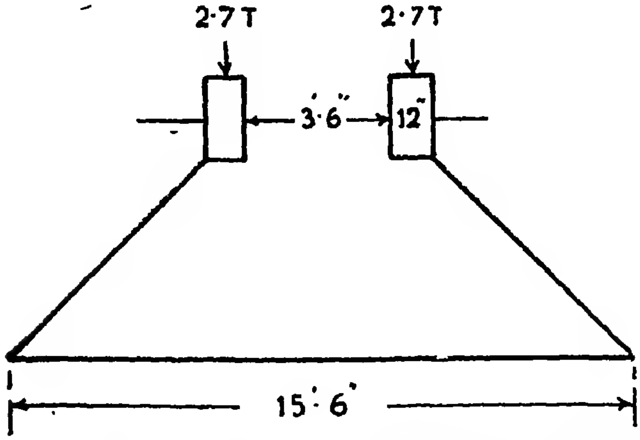


Reaction at 10′ distance from the Crown for 4.2 ton Load $= \frac{4.2}{12.5} = 0.336$ ton/ft.



Reaction at 20′ from the Crown for 12 T load $= \frac{12}{14} = .857$ ton/ft.

Reaction at 20′ distance from the Crown for 5.4T Load $= \frac{5.4}{15.5} = .348$ ton/ft.



Reaction at 20′ distance from Crown for (4.2T Load) $= \frac{4.2}{15.5} = .271$ ton/ft.

When the depth of filling is more than 4′ load is taken as uniformly distributed.

Uniformly distributed load (for 5.4^T, 5.4^T & 5.4^T load at sections where depth of filling is more than 4′—0″) $= \frac{5.4 \times 3}{15.5 \times 27} = .0387$ tons per sq. ft.

Uniformly distributed load. (For 5.4^T, 5.4^T and 12^T load at sections where the depth of filling is more than 4′—0″) $=\left(\frac{5.4}{15.5}+\frac{5.4}{15.5}+\frac{12}{14}\right)/27=0.0576$ tons/ft².

Uniformly distributed load. (For 5.4^T, 12^T & 4.2^T load at sections where the depth of filling is more than 4′—0″) $=\left(\frac{5.4}{15.5}+\frac{12}{14}+\frac{4.2}{15.5}\right)/27=0.0546$ tons/ft².

Uniformly distributed load. (For 5.4^T, 4.2^T & 5.4^T, load at sections where the depth of filling is more than 4′) $=\left(\frac{5.4}{15.5}+\frac{5.4}{15.5}+\frac{4.2}{15.5}\right):27=0.0358$ tons per sq. ft.

SECTIONS	DEAD LOAD Uniformly distributed lbs/ft²	RESULTANT DEAD LOAD lbs.
I	4140	20674
II	3100	17030
III	2040	12860
IV	1360	8860
V	928	6500
VI	670	4800
VII	491	3600
VIII	428	3140

Dead Load Horizontal thrust

$$
\begin{aligned}
20674 \times 0.02 &= 415 \\
17030 \times 0.099 &= 1690 \\
12860 \times 0.256 &= 3300 \\
8860 \times 0.466 &= 4140 \\
6500 \times 0.698 &= 4540 \\
4800 \times 0.93 &= 4460 \\
3600 \times 1.13 &= 4060 \\
3140 \times 1.24 &= 3900 \\
\hline
&\ 26505
\end{aligned}
$$

$\therefore$ Total Dead load horizontal thrust $= 26505 \times 2$

$= 53010$ lbs.

Dead load B.M. is calculated as given below.

Dead load B. M. at Springing

$$
\begin{aligned}
20764 \times 22\ 24 &= 461{,}000 \\
17030 \times 57.22 &= 977{,}000 \\
12860 \times 72.0 &= 927{,}000 \\
8860 \times 68 &= 602{,}000 \\
6500 \times 46.5 &= 302{,}000 \\
4800 \times 11.5 &= 55{,}200 \\
\hline
&\ -3{,}324{,}200
\end{aligned}
$$

$$
\begin{aligned}
3600 \times 30.5 &= 110000 \\
3140 \times 68.5 &= 215000 \\
3140 \times 95.9 &= 302000 \\
3600 \times 107.0 &= 386000 \\
4800 \times 99.85 &= 479000 \\
6500 \times 83\ 4 &= 542000 \\
8860 \times 60.5 &= 535000 \\
12860 \times 35.125 &= 453000 \\
17030 \times 14.14 &= 242000 \\
20764 \times 20.91 &= 60000 \\
\hline
&\ -3324000
\end{aligned}
$$

Total dead load B.M.

$= -3324200 + 3324000$

$= -200$ which is negligible.

MAXIMUM B. M. AT SPRINGING.

(Due to Live load)

$\frac{-44.48\times5}{2} = 111.1$

$\frac{-44.48-70.0}{2}\times5.5=315.0$ $\qquad 0.857\times10=8.57$

$\frac{-70.0-74.0}{2}\times6.32=455.0$ $\qquad 0.0358\times1537.1=55.0$

$\qquad\qquad 63.57$ in tons.

$\frac{-74.0-62.0}{2}\times6.5=442.0$ $\qquad \therefore$ maximum negative live load B.M.

$\frac{-62.0-47.0}{2}\times3.68=214.0$

$\qquad 1537.1$

$=63.57$ in tons

$=-143000$ in lbs.

$\frac{5.82\times5}{2}=14.53$ $\qquad 0.0387\times927.2=36.0$

$\frac{5.82+22.45}{2}\times5.5=77.7$ $\qquad 0.515\times84=43.2$

$\frac{22.45+47.8}{2}\times6.32=222$ $\qquad 1.09\times107=117.0$

$\frac{47.8+73.3}{2}\times6.5=394$ $\qquad 0.271\times93=25.2$

$\frac{73.3+83}{2}\times3.68=288$ $\qquad 0.432\times31=13.4$

$\qquad 927.2$ $\qquad 234.8$ in tons.

Maximum Positive Live load B.M. $=234.8$ in tons $=+527000$ in lbs.

HORIZONTAL THRUST AT SPRINGING.

(Longitudinal Strip of Slab 1′ wide).

$0.0358\times7.644=0.273.$

$0.857\times0.91=0.78.$

$\qquad 1.053$

Corresponding H. T. due to live load causing maximum negative B.M. At Springing $=1.053$ tons $=2360$ lbs.

$0.0387\times7.644=0.295$

$0.515\times1.26=0.65$

$0.109\times1.13=1.23$

$0.271\times0.91=0.246$

$0.432\times1.13=0.49$

$\qquad 2.911$ tons.

Corresponding H.T. due to live load causing maximum positive B.M. at Springing $= 2.911$ tons.
$= 6520$ lbs.

DEAD LOAD B. M. (CENTRE SECTION).

$$
\begin{aligned}
20674 \times -0.52 &= -10800\\
17030 \times -2.35 &= -40000\\
12860 \times -5.28 &= -68000\\
8860 \times -7.25 &= -64200\\
6500 \times -5.45 &= -35400\\
\hline
&\quad -218400
\end{aligned}
$$

$$
\begin{aligned}
4800 \times +1.95 &= +9360\\
3600 \times +17.7 &= +64000\\
3140 \times +46.1 &= +145000\\
\hline
&\quad 218{,}360
\end{aligned}
$$

Total Dead load B.M. at centre section $= 2\,(-218400+218360)$
$= 2 \times -40$
$= -80$ in lbs.
which is negligible.

MAXIMUM B. M. (CENTRE SECTION).

Due to Live load :

$$
\begin{aligned}
\frac{-5.4-7.6}{2} \times 3.68 &= -23.9\\
\frac{-7.6-6.9}{2} \times 6.5 &= -47.0\\
\frac{-6.9-3.65}{2} \times 6.32 &= -33.4\\
\frac{-3.65-1.04}{2} \times 5.5 &= -12.9\\
-1.04 \times 5 &= -\ 2.6\\
\hline
&\quad 119.8
\end{aligned}
$$

$=$ Area under uniformly distributed load

$$
\begin{aligned}
1.33 \times 64 &= 85.0\\
.432 \times 24 &= 10.4\\
0.336 \times 24 &= 8.06\\
0.348 \times -0.1 &= -0.0348\\
0.348 \times -0.1 &= -0.0348\\
0.0387 \times 119.8 &= -4.65\\
0.0387 \times 119.8 &= -4.65\\
\hline
&+103.46 \text{ in tons}\\
&-9.996 \text{ in tons.}
\end{aligned}
$$

Therefore Maximum Positive live load B. M.
$= 103.46$ in tons.
$= 103.46 \times 2240$
$= 234000$ in lbs.

Maximum Negative live load B. M.
$= -9.996$ in tons
$= -9.996 \times 2240$
$= 22400$ in lbs.

Horizontal Thrust.

At the Crown : (Longitudinal strip of slab 1′ wide). Due to Live load (causing Maximum B. M. at the crown).

$$1.33 \times 1.26 = 1.67$$
$$0.432 \times 1.13 = 0.485$$
$$0.336 \times 1.13 = 0.38$$
$$\overline{2.535} \text{ tons.}$$

$$0.348 \times 0.91 = 0.316$$
$$0.348 \times 0.91 = 0.316$$
$$0.0387 \times 7.644 = 0.296$$
$$0.0546 \times 7.644 = 0.417$$
$$\overline{1.345}$$

$$\frac{0.04 \times 5}{2} = 0.100$$
$$\frac{0.04 + 0.158}{2} \times 5.5 = 0.544$$
$$\frac{0.158 + 0.354}{2} \times 6.32 = 1.630$$
$$\frac{0.354 + 0.577}{2} \times 6.5 = 3.020$$
$$\frac{0.577 + 0.7}{2} \times 3.68 = 2.350$$
$$\overline{7.644}$$

Corresponding H.T. due to live load causing maximum B. M. at the Crown
=2.535 tons
=5670 lbs.

Corresponding H.T. due to live load causing maximum negative B. M. at the Crown=1.345 tons
=3020 lbs.

Variation of Temperature.

(*Vide* "Reinforced Concrete Bridges" by W. L. Scott.)

"When an arch is subjected to a change in temperature it undergoes an alteration in length. If the abutments are immovable the span between them remains unchanged. It therefore results that the arch exerts a thrust or a "pull" upon the Abutments accordingly as the length of the arch is increased or decreased."

"Actually, of course, the Arch will never exert a pull on the Abutments; since the thrust due to vertical loading will always be greater force causing an opposite thrust to be exerted upon the arch by the abutments. The "Pull" mentioned above will effect a reduction of thrust and the resultant moment induced in the Arch needs to be added algebrically to those produced by the super-imposed loading."

Now the change in the length of the span if the Rib were free to expand or contract would be $=nl$

Where n is the change in length per unit of length and l is the span of the arch.

As the span cannot change in length because of the Rigidity of the abutments Total Horizontal displacement is zero.

$$\int_A^B \frac{Myds}{EI} \pm nl - \int_A^B \frac{H}{AE}dx = 0$$

And as there can be no change in the level of the supports.

Total Vertical Displacement $=0$

$\int_A^B \frac{Mx}{EI}ds = 0.$ And also as there can be no rotation of the end sections.

Total angular displacement $=0$

$\int_A^B \frac{M}{EI}ds = 0.$ In a symmetrical Rib the B.M. in the Arch Sections produced by a linear variations is $Mt = -Hy + Hqa.$

$H.qa$ is the end fixing moment and since horizontal forces only are considered qa is the height of the point of application of horizontal thrust above the level of both springings.

$$\int_A^B \frac{Myds}{EI} \pm nl - \int_A^B \frac{H}{AE}dx = -\int_A^B \frac{Hy^2ds}{EI} + \int_A^B \frac{Hqayds}{EI} \pm nl$$

$$-\int_A^B \frac{H}{AE}dx = 0$$

$$\int_A^B \frac{Mx}{EI}ds = -\int_A^B \frac{Hxyds}{EI} + \int_A^B \frac{H.qa.xds}{EI} = 0.$$

Employing the assumption with regard to the curve of the arch axis *i.e.* $I = I_c \operatorname{Sec} \propto$ where I_c is the moment of Inertia at the crown and $\propto$ is the angle which the arch axis makes with the horizontal and E is a constant.

We have by multiplying throughout by E & I_c, $\int_A^B Mydx \pm E.I_c.\ n.l.$

$$-H.I_c \int_A^B \frac{dx}{A} = -H\int_A^B y^2\,dx + Hqa\int_A^B ydx \pm E.I_c.n.l. - HI_c\int_A^B \frac{dx}{A} = 0.$$

$$\int_A^B Mx\,dx = -H\int_A^B x.y.\,dx + H.qa\int_A^B x.\,dx = 0.$$

On further Reduction we have:

$$\int_A^B Mydx \pm E.\ I_c\,n.\ l. - H.\ I_c\int_A^B \frac{dx}{A} =$$

$$-H.\ \tfrac{8}{15}\ f^2l + H.qa.\ \tfrac{2}{3}fl \pm E.I_c.\ n.l. - \frac{H.\ I_c.l}{Av} = 0 \ldots\ldots(1)$$

$$\int_A^B Mxdx \times -\frac{Hfl^2}{3} + Hqa\frac{l^2}{2} = 0 \ldots\ldots(2).$$

From Equations (1) and (2) :—

$$H\left(\tfrac{4}{45}f^2+\frac{I_c}{Av}\right)\pm E.\,I_c.\,n=0$$

$$\therefore H=\pm\frac{45.\,E.\,I_c.\,n}{4f^2+45\frac{I_c}{Av}}$$

$$\text{or, Horizontal thrust}=\pm\frac{45.\,n.\,E.\,I_c}{4f^2}$$

The factor $\left(\frac{45\ I_c}{Av}\right)$ is small in comparison with $4f^2$ and so it is neglected.

A 'Rise' of Temperature produces an increased thrust on the Abutments and causes a negative bending moment above the level of the Elastic Centre and a positive bending moment below this level.

Conversly, a similar fall in temperature reduces the thrust upon the abutment and produces bending moments equal in amount but of opposite sign to that caused by a rise in temperature.

Maximum variation from the mean temperature is taken as 30° F.

$n=0.000006\times 30=0.00018$

E = Co-efficient of elasticity of concrete = 2000000 lbs/ in².

$$H=\pm\frac{45.n.E.Ic}{4f^2}\quad\text{Due to temperature.}$$

$$Ic=\text{Moment of Inertia of concrete}=\frac{1}{12}\times 12\times 21^3=9300\ \text{in}^4.$$

Moment of Inertia of Steel

$$=(m-1)\times 2\times 0.66\times(10.5-1.2)^2$$
$$=14\times 2\times .66\times 9.3^2$$
$$=1600\ \text{in.}^4$$

Total Equivalent Moment of Inertia

$$=9300+1600$$
$$=10900\ \text{in.}^4$$

$f=264$

$$\therefore\ H=\pm\frac{45\times 0.00018\times 2000000\times 10900}{4\times 264\times 264}$$
$$=\pm 635.$$

$$\text{B. M. at Crown}=635\times(264-214)$$
$$=635\times 50=31800\ \text{in lbs.}$$

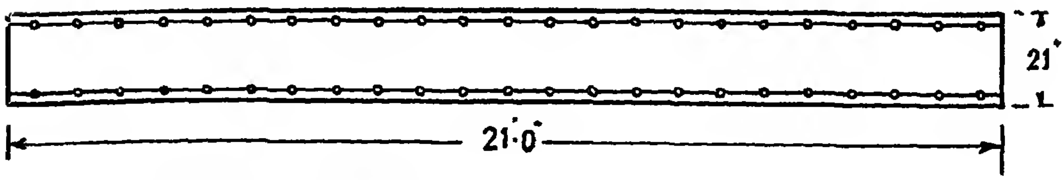
$$\text{B. M. at Springing}=635\times(0-214)$$
$$=635\times -214$$
$$=-136000\ \text{in lbs.}$$

MAXIMUM B. M. AND CORRESPONDING THRUSTS.

At Crown	Positive B.M. in lbs.	Corresponding Thrusts lbs.	Negative B.M in lbs.	Corresponding Thrusts lbs.
Dead Load	0	53010	0	53010
Live Load	234000	5670	−22400	3020
Temperature	31800	−635	−31800	635
Total	265800	58045	−54200	56665

At Springing.	Positive B.M.	Corresponding Thrusts.	Negative B.M.	Corresponding Thrusts.
Dead Load	0	53010	0	53010
Live Load	527000	6520	−143000	2360
Temperature	136000	637	−136000	−637
Total	663000	60167	−279000	54733

CENTRE SECTION.



Area of steel (top) = 13.8 in²

Area of steel (Bottom) = $\frac{13.8 \text{ in}^2}{27.6 \text{ in}^2}$

Area of concrete = 21 × 12 × 21 = 5280 in²

Taking $M=15$ we have Total area $F=5280$

$$\frac{386}{5666 \text{ sq. in.}}$$

$27.6\times14=386$ sq. in.

Total Moment of the Inertia of the Section

$=\frac{1}{12}\times21\times12\times21^3$

$=197000$ plus $14\times27.6\times9.3^2=34000$ *i.e.*, 231000 in^4

Taking Longitudinal Strip of Slab 1′ wide

Area of Secton $=\frac{5666}{21}=268$ sq. in.

Moment of Inertia of the Section $=\frac{231000}{21}=11100$ in^4.

For positive B.M.

Maximum positive B.M. $=265800$

Corresponding Thrust $N=58045$ lbs.

Maximum Compressive Stress $=\frac{58045}{268}+\frac{265800\times10.5}{11100}$

$\frac{N}{A}+\frac{My}{I}=216+251=467$ lbs. per sq. in.

Maximum Tensile stress $=216-251=-35$ lbs. per sq. in.

(For negative B.M.)

maximum negative B.M. $=54200$ in lbs.

Corresponding Thrust $N=56665$ lbs.

Minimum Compressive Stress $=\frac{N}{A}-\frac{My}{I}$

$=\frac{56665}{268}-\frac{54200\times10.5}{11100}$

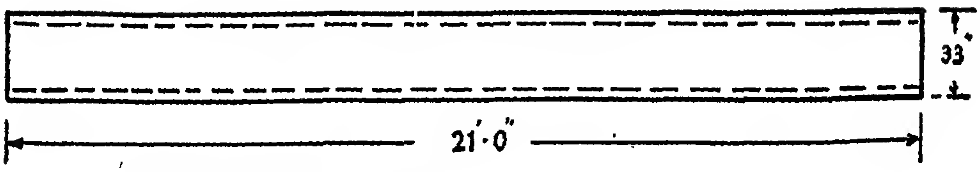
$=211-51$

$=160$ lbs. per sq. in.

Maximum Compressive Stress $=211+51$

$=262$ lbs. per sq. in.

SPRINGING SECTION.



Area of steel (top) $=13.8$ in^2

Area of steel (bottom) $=13.8$

27.6 in^2

Area of concrete $= 21 \times 12 \times 33$
$= 8260$ sq. in.

Taking $m=15$, we have Total Area $F = 8260$
386
8646 sq. in.

Total Moment of Inertia of the Section $= \frac{1}{12} \times 21 \times 12 \times 33^3$
$= 772000$ plus $14 \times 27.6 \times 15.3^2$
$= 92000$ *i.e.* 864000 in^4.

Taking longitudinal strip of slab 1′ wide

Area of Section $= \frac{8646}{21} = 412$ sq. in.

Moment of Inertia of the Section $= \frac{864000}{21} = 41200$ in^4.

For Positive B.M.

Maximum B.M. 663000 in lbs.

Corresponding Thrust $N = 60167 \times 1.59$ lbs.

Maximum Compressive Stress $= \frac{N}{A} + \frac{My}{I}$

$$= \frac{60167 \times 1.59}{412} + \frac{663000 \times 16.5}{41200}$$

$= 232 + 264 = 496$ lbs. per sq. in.

Maximum Tensile Stress $= 232 - 264 = -32$ lbs. per sq. in.

For Negative B.M.

Maximum B.M. $= 279000$ in. lbs.

Corresponding Thrust $N = 54733 \times 1.59$ lbs.

Minimum Compressive Stress $= \frac{N}{A} + \frac{My}{I}$

$$= \frac{54733 \times 1.59}{412} - \frac{279000 \times 16.5}{41200}$$

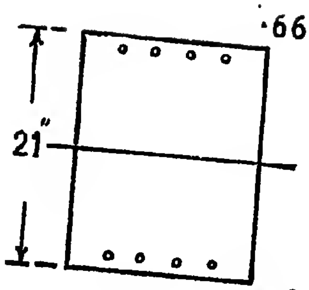
$= 211 - 111$
$= 100$ lbs. per sq. in.

Maximum Compressive Stress $= 211 + 111$
$= 322$ lbs. per sq. in.

Similar calculations were made for other intermediate sections

Maximum Stresses at the Crown.

For Positive B. M.



$$A = 12 \times 21 + 14 \times 2 \times .66$$
$$= 252 + 18.5$$
$$= 270.5 \text{ sq. in.}$$

$$I = \tfrac{1}{12} \times 12 \times 21^3 + 18.5 \times 9.3^2$$
$$= 9300 + 1600$$
$$= 10900 \text{ in}^4.$$
$$M = 265800$$

$$\begin{array}{r} 10{\cdot}5 \\ \underline{1{\cdot}2} \\ 9{\cdot}3 \end{array}$$

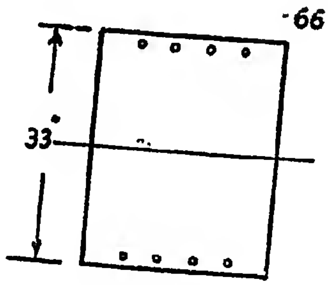
Normal Thrust $N = H = 58045$ lbs.

Maximum Compressive Stress $= \dfrac{N}{A} + \dfrac{My}{I}$

$$= \frac{58045}{270.5} + \frac{265800 \times 10.5}{10900}$$
$$= 215 + 256$$
$$= 471 \text{ lbs. per sq. in.}$$

Tensile $= 215 - 256 = -41$ lbs. per sq. in.

MAXIMUM STRESS AT SPRINGING.



$$A = 396 + 14 \times 2 \times .66$$
$$= 396 + 18.5$$
$$= 414.5 \text{ sq. in.}$$

$$I = \tfrac{1}{12} \times 12 \times 33^3 + 18.5 \times 15.3^2$$
$$= 36000 + 4320$$
$$= 40320$$

Normal Thrust $N = 60165 \times 16.5$
$= 99000$ lbs.

$$\begin{array}{r} 16.5 \\ \underline{1.2} \\ 15.3 \end{array}$$

$$f = \frac{N}{A} + \frac{My}{I}$$
$$= \frac{99000}{414.5} + \frac{663000 \times 16.5}{40320}$$
$$= 240 + 272 = 512 \text{ lbs.}$$
$$f' = 240 - 272$$
$$= -32 \text{ lbs. per sq. in.}$$

$$\begin{array}{r} 36000 \\ \underline{4320} \\ 40320 \end{array}$$

$$\begin{array}{r} 272 \\ \underline{240} \\ 32 \end{array}$$

Similar calculations were made for other intermediate sections.

ABUTMENTS.

(*Vide* Plate No. 6.)

Let us consider the case when the abutment is under water up to DR. For calculating the weight of the abutment and its centre of gravity the abutment is divided into eight parts as in the sketch.

$P_1=$ weight of $ABCD=12.50\times28.25\times21\times125 = 908000$ lbs.

$P_2= \quad BEGC=9\times28.25\times21\times140 = 750000$ lbs.

$P_3= \quad FGR=\frac{3}{2}\times24.6\times21\times140 = 109000$ lbs.

$P_4= \quad DRHL=24.75\times25.45\times21(140-62.5)=1026000$ lbs.

$P_5= \quad RHK=\frac{2.5}{2}\times22\times21\times77.5 = 448000$ lbs.

$P_6= \quad DLM=\frac{1.7}{2}\times25.5\times21\times77.5 = 353000$ lbs.

$P_7= \quad NMKO=29.5\times3\times21\times77.5 = 145000$ lbs.

$P_8= \quad NOQP=34.04\times2\times21\times62.5 = 89500$ lbs.

Total 3107600 lbs.

The moment of these weights about P.

$$\Sigma Px=908000\times10.375+750000\times21.25+109000\times27.75+1026000\times16.37+448000\times30.75+353000\times3.4+(145000+89500)\,17.02$$
$$=50715000 \text{ ft. lbs.}$$

Vertical Pressure from the Arch is $77464\times21+995000=1720000$ lbs. and acts 4′ from P.

Horizontal thrust from the arch is 1282000 due to the Dead load and Live load and acts 37′ above the base.

Let the Reaction cut the base $\bar{x}$ away from P

$$\bar{x}=\frac{50715000+1720000\times4+1282000\times37}{3107600+1720000}$$
$$=\frac{105045000}{4827600}=21.7 \text{ ft.}$$

As the base is 34.04′ the eccentricity is $21.7-17.02=4.68$ ft.

This is well within the middle third. No effect of the Earth Pressure has been considered since not only is it small but also it helps in counteracting the thrust and thus in bringing the Resultant nearer the centre.

If the water level is lowered the Dead weight is increased thus reducing the eccentricity.

WING WALLS.

(*Vide* Plate No. 7.)

See Sketch I. Vertical Weight :—

$0.75 \times 3.625 \times 100 = 272$		
$0.75 \times 24 \times 140 = \underline{2520}$	2792	
$0.75 \times 5.625 \times 100 = 422$		
$0.75 \times 22 \times 140 = \underline{2300}$	2722	
$0.75 \times 7.625 \times 100 = 572$		
$0.75 \times 20 \times 140 = \underline{2100}$	2672	
$0.75 \times 9.625 \times 100 = 722$		
$0.75 \times 18 \times 140 = \underline{1890}$	2612	
$0.75 \times 11.625 \times 100 = 875$		
$0.75 \times 16 \times 140 = \underline{1680}$	2555	
$0.75 \times 13.625 \times 100 = 1020$		
$0.75 \times 14 \times 140 = \underline{1470}$	2490	
$0.75 \times 15.625 \times 100 = 1175$		
$0.75 \times 12 \times 140 = \underline{1260}$	2435	
$0.75 \times 17.625 \times 100 = 1320$		
$0.75 \times 10 \times 140 = \underline{1050}$	2370	
$0.75 \times 19.625 \times 100 = 1470$		
$0.75 \times 8 \times 140 = \underline{840}$	2310	
$0.75 \times 21.625 \times 100 = 1620$		
$0.75 \times 6 \times 140 = 630$	2250	
$0.75 \times 23.625 \times 100 = 1770$		
$0.75 \times 4 \times 140 = \underline{420}$	2190	
$0.75 \times 25.625 \times 100 = 1920$		
$0.75 \times 2 \times 140 = \underline{210}$	2130	
$0.75 \times 27.625 \times 100 =$	2070	
$0.5 \times 27.625 \times 140 =$	5800	
$\frac{1.85}{2} \times 27.625 \times 140 =$	3580	
$2 \times 134.8 \times 125 =$	$\underline{3480}$	
	44458	lbs.

Taking first moment about C we have :

$$2070\times0.375+2130\times1.125+2190\times1.875+2250\times2.625$$
$$+2310\times3.375+2370\times4.125+2435\times4.875+2490\times5.625$$
$$+2555\times6\ 375+2612\times7.125+2672\times7.875+2722\times8.625$$
$$+2792\times9.375+5800\times10.5+3580\times11.87+3480\times6.925$$
$$=780+2400+4100+5920+7800+9800+11850+14000+16250$$
$$+18600+21000+23500+26100+61000+42500+24000$$

$$\bar{x}=\frac{289600}{44458}=6.5'$$

Earth Pressure :—

$$=\tfrac{1}{2}\,Ph^2\,\frac{1-\text{Sin}\,\phi}{1+\text{Sin}\,\phi}. \qquad \phi=40^o$$

$$=\tfrac{1}{2}\times100\times29.62^2\times\frac{1-.64}{1+.64} \qquad \text{Sin}\,\phi=.64.$$

$$=9650 \text{ lbs.}$$

$$x=\frac{29.62}{3}=9.87'$$

The Resultant passes through the middle third.

Overturning :—

The factor of safety against overturning $=\frac{17.2}{5.2}=3.3$ which is safe.

Sliding :—

$$\text{Tan}\propto=\frac{H}{V}=\frac{9650}{44458}$$
$$=0.217$$

This is less than .4 and so it is safe.

WING WALL (*Continued*).

SECTION II

Vertical Weight :—

$0.75\times 3.625\times 100=272$	
$0.75\times 10\times 140=\underline{1050}$	1322 lbs.
$0.75\times 5.625\times 100=422$	
$0.75\times 8\times 140=\underline{840}$	1262 ,,
$0.75\times 7.625\times 100=572$	
$0.75\times 6\times 140=\underline{630}$	1202 ,,
$0.75\times 9.625\times 100=722$	
$0.75\times 4\times 140=\underline{420}$	1142 ,,
$0.75\times 11.625\times 100=875$	
$0.75\times 2\times 140=\underline{210}$	1085 ,,
$0.75\times 13.625\times 100=1020$	1020 ,,
$1.75\times 13.625\times 140=2870$	2870 ,,
$.91\times \frac{13.625}{2}\times 140=870$	870 ,,
$2\times 7.66\times 125=1920$	1920 ,,
	12693 lbs.

Taking first moment about cc

$1020\times .375+1085\times 1.125+1142\times 1.875+1202\times 2.625+1262\times 3.375+1322\times 4.125+2870\times 5.25+870\times 6.3+1920\times 3.83=$
$382+1220+2140+3170+4260+5460+15100+5500+7360$
$=44592$

$$\bar{x}=\frac{44592}{12693}=3.52'$$

.375	5.250
.75	.75
1.125	6.00
.75	.3
2.625	6.30
.75	.60
3.375	6.90
.75	.75
4.125	2) 7.66
1.125	3.83
5.250	

Earth Pressure.

$$=\tfrac{1}{2}\ Ph^2\,\frac{1-\text{Sin }\phi}{1+\text{Sin }\phi}$$

$\phi=40^\circ$
Sin $\phi=0.64.$

$$=\tfrac{1}{2}\times 100\times 15.625^2\times\frac{0.36}{1.64}$$

$=2700$ lbs.

$x=15.625/3=5.208.$

The Resultant of Vertical weights and the Earth Pressure passes through the middle third.

Overturning

Overturning moment $=2700\times 5.208' = 14100$ ft. lbs.

Resisting moment $=12693\ (7.66-3.52)$

$=12693\times 4.14$

$=52500$ ft. lbs.

Factors of Safety $=\frac{52500}{14100}=3.7$ which is safe.

Sliding

The angle which the resultant makes with the vertical $=\propto$ where tan $\propto=\frac{H}{V}=\frac{2700}{12693}=0.213$

This is less than the co-efficient of Friction (0.4.)

Co-efficient of Friction

$\tan\propto=\tan 22^\circ$ say $=\frac{3.25}{9.3}=0.4$

STABILITY OF PIER.

(Vide Plate No. 8.)

Minimum vertical reaction due to live load :—

$$\frac{1+0.994}{2}\times 5 \quad =4.99 \qquad\qquad \frac{0.0057\times 5}{2} \quad =0.0142$$

$$\frac{0.994+0.975}{2}\times 5.5 \quad =5.40 \qquad\qquad \frac{0.0057+0.0246}{2}\times 5.5 \quad =0.0835$$

$$\frac{0.975+0.939}{2}\times 6.32=6.05 \qquad\qquad \frac{0.0246+0.0606}{2}\times 6.32 \quad =0.269$$

$$\frac{0.939+0.887}{2}\times 6.5 \quad =6.94 \qquad\qquad \frac{0.0606+0.1130}{2}\times 6.5 \quad =0.565$$

$$\frac{0.887+0.85}{2}\times 3.68=3.19 \qquad\qquad \frac{0.1130+0.150}{2}\times 3.68 \quad =0.30$$

Area under uniformly distributed load. $=\overline{25.57}$ in^2 Area under uniformly distributed load. $=\overline{1.2317}$ in^2

$$
\begin{aligned}
0.348 &\times 0.81 &&=0.282\\
0.432 &\times 0.69 &&=0.298\\
0.515 &\times 0.5 &&=0.258\\
0.432 &\times 0.35 &&=0.151\\
0.348 &\times 0.20 &&=0.0697\\
0.0387 &\times 25.57 &&=0.9900\\
0.0546 &\times 1.2317 &&=\underline{0.0675}\\
& && 2.1162 \text{ tons.}
\end{aligned}
$$

See Influence line for "V"

Total minimum vertical Reaction due to live load $=2.1162\times 2240\times 20$ lbs.
$=95000$ lbs.

Maximum Horizontal Thrust due to Live Load.

$$\frac{0.668+0.54}{2}\times 3.68=2.22$$

$$\frac{0.54+0.325}{2}\times 6.5 \quad =2.81$$

$$\frac{0.325+0.144}{2}\times 6.32=1.48$$

$$\frac{0.144+0.0361}{2}\times 5.5 \quad =0.495$$

$$\frac{0.361}{2}\times 5 \quad =\underline{0.0902}$$

Area under uniformly distributed load $=7.0952$ in^2

$1.33 \times 1.24 = 1.650$
$0.432 \times 1.11 = 0.480$
$0.336 \times 1.11 = 0.374$
$0.348 \times 0.841 = 0.292$
$0.0387 \times 7.0952 = 0.274$
$0.0387 \times 7.0952 = 0.274$
3.636 tons.

Total maximum Horizontl thrust due to live load $= 3.636 \times 20 \times 2240$
$= 163000$ lbs.

WEIGHT OF PIER.

BATTERED PORTION.

Area of top $= 8 \times 10.5 + \frac{\pi}{4} \times 8^2$
$= 84 + 50 = 134$ sft.

Area of Bottom $= 10.7 \times 31.7 + \frac{\pi}{4} \times 11^2$
$= 340 + 95$
$= 435$ sft.

Volume of Battered Portion $= (134 + 435)8$
$= 569 \times 8 =$ 4550cft.
+Volume below battered portion 1369cft.
Total volume = 5919cft.

$15 \times 36 \times 1 = 540$
$13 \times 34 \times 1 = 445$
$11.7 \times 32.7 \times 1 = 384$

Volume below Battered portion 1369 cft.

Weight of Pier $= 5919 \times 125$
$= 7,40,000$ lbs.

$20674 + 17030 + 12860 + 8860 + 6500 + 4800 + 3600 + 3140 = 77464$ lbs.

Dead load (for Longitudinal Strip of Slab 1′ wide) $= 77464 \times 2 = 154928$ lbs.

Total Dead Load Reaction $= 154928 \times 21$
$= 3240,000$ lbs.

$20674 \times 0.018 = 371.0$
$17030 \times 0.09 = 1530.0$
$12860 \times 0.2345 = 3020.0$
$8860 \times 0.4325 = 3830.0$
$6500 \times 0.6615 = 4300.0$
$4800 \times 0.892 = 4280.0$
$3600 \times 1.09 = 3930.0$
$3140 \times 1.205 = 3790.0$
25051.0

Corresponding horizontal thrust due to Dead Load $= 50102 \times 20$
$= 1002040$ lbs.

H. T. $= 25051 \times 2$
$= 50102$ lbs.

(For Longitudinal Strip of Slab 1′ wide)

Dead Load Horizontal Thrust on the pier from opposite side balances.

Dead Load Vertical Reaction=3240,000 lbs.

Weight of Pier.=740,000

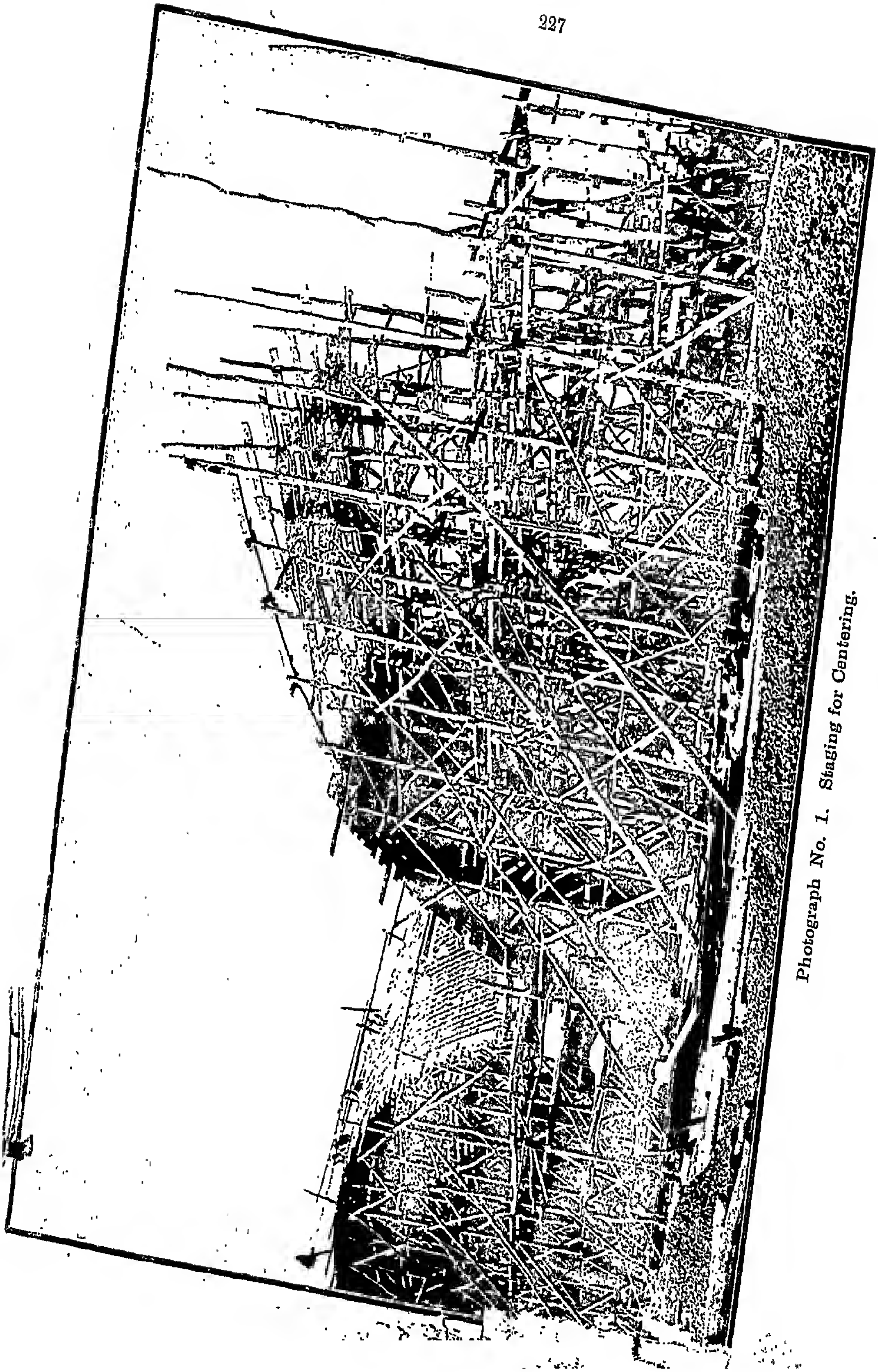
Total =39,80,000 lbs

Taking Account of buoyancy Total Vertical Reaction (acting through the Centre line of Pier)=19,90,000 lbs.

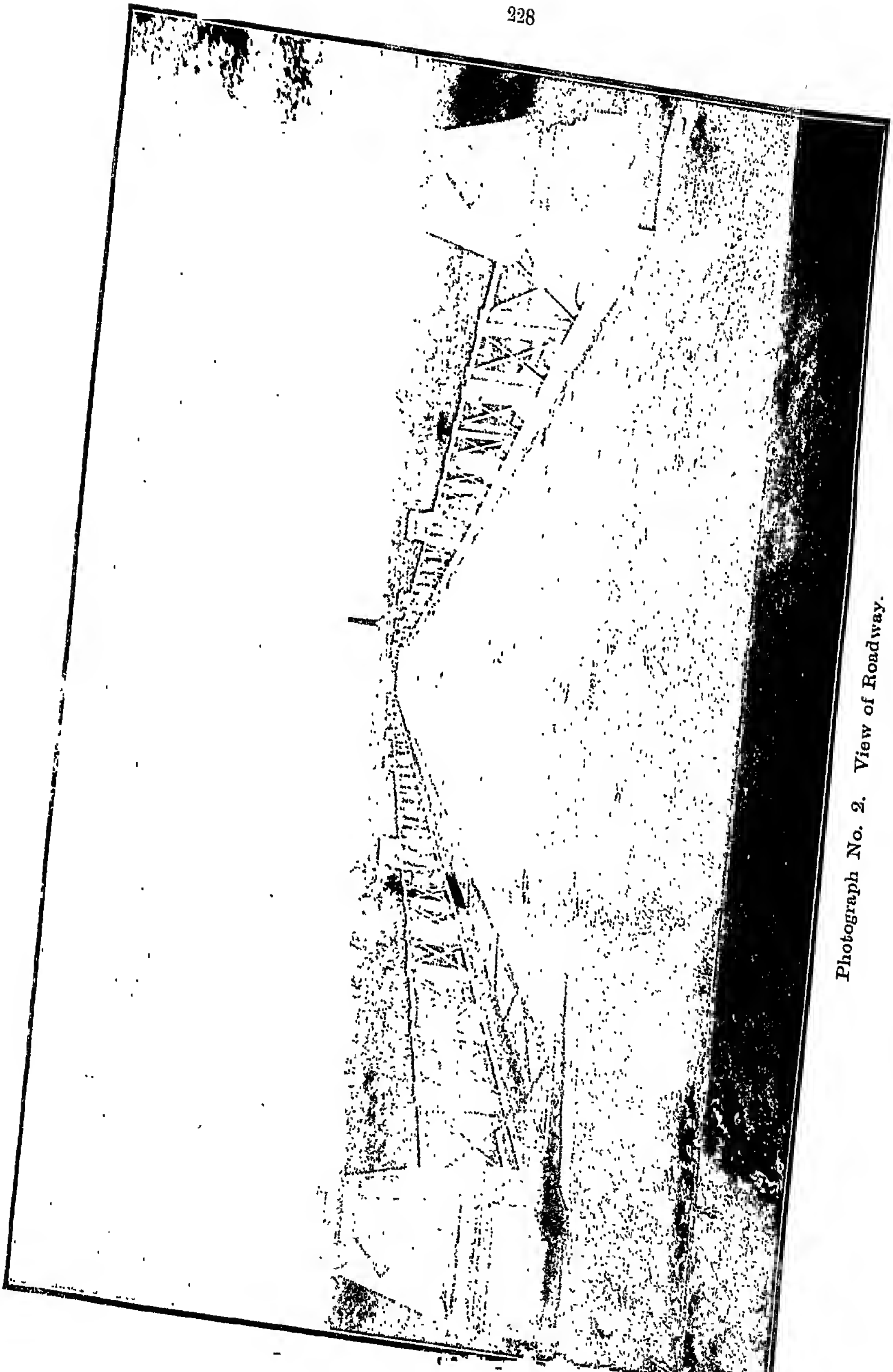
Minimum Live load reaction=95,000 lbs.

Maximum Horizontal Thrust (due to live load)=1,63,000 lbs.

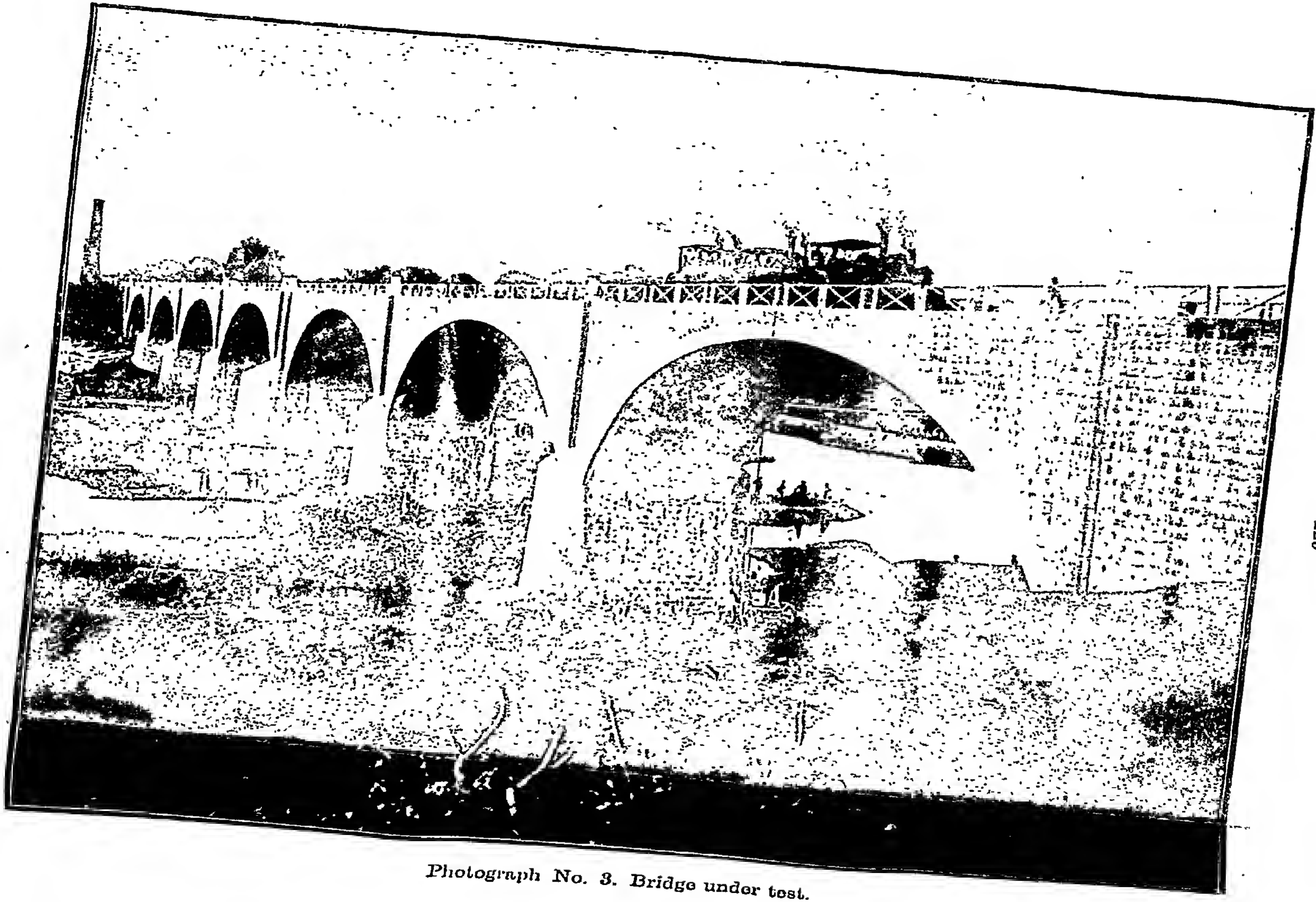
So from the figure it will be seen that the Resultant thrust passes within the middle third.



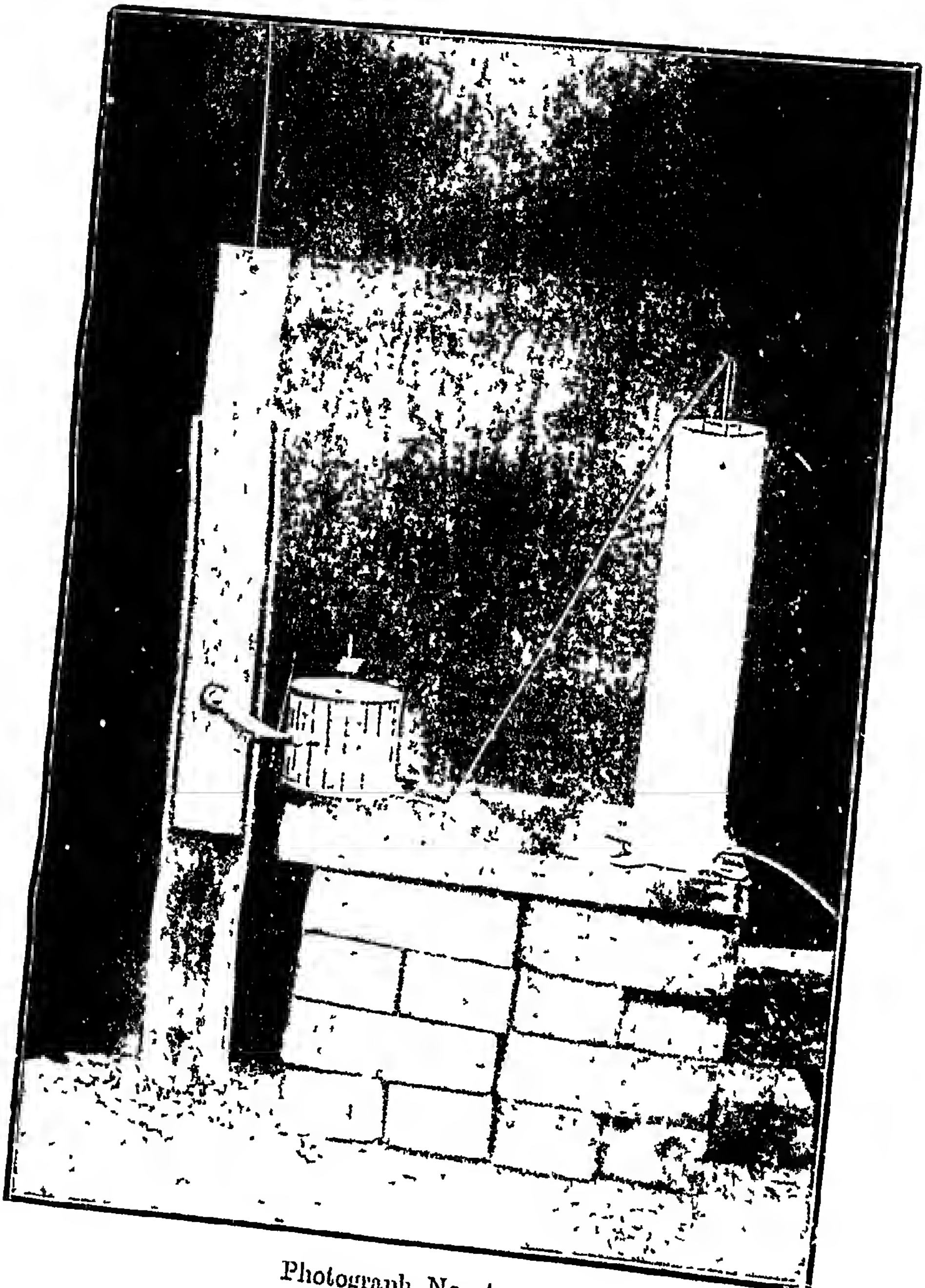
Photograph No. 1. Staging for Centering.



Photograph No. 2. View of Roadway.



Photograph No. 3. Bridge under test.



Photograph No. 1.
Test Recording apparatus.

DISCUSSIONS ON PAPER No. 38.

Rai Bahadur S. N. Bhaduri (Author) :—I introduce the paper which is already before you.

Mr. G. M. McKelvie (Central Provinces) :—Mr. Chairman and Gentlemen.—As a delegate from the Central Provinces I have read the paper with peculiar interest. The Central Provinces claim to have pioneered in India on the design and construction of submersible bridges and a few remarks on the difference between current trends in design and practice in the Central Provinces and those indicated in the paper under discussion might be of general interest.

But first, I would like to make a few general remarks. From the description of the site it is not clear that a submersible bridge was really necessary. Generally speaking, a submersible bridge is required only in rivers which regularly over-top their banks in high flood, and then only when it is not economical to make banked approaches and a bridge which will pass the full discharge of the catchment. A typical submersible bridge in the Central Provinces is the bridge over the Nerbudda near Jubbulpore. The formation level of this bridge is 40 feet above the bed but the highest known flood was 78 feet above the bed level. Nevertheless, this bridge is over-topped by floods for two or three days only during a normal monsoon. This submersible bridge with its approaches cost nearly Rs. 7 lakhs while the railway high level bridge a few miles down stream and constructed at the same time cost more than Rs. 44 lakhs.

Assuming, however, that a submersible bridge would be. cheaper than a high level bridge at this site, it would be interesting to know the reasons which led to the adoption of a span of 103 feet. With trap rock so near the surface it appears possible that a bridge with shorter spans would have been cheaper if designed so that the cost up to springing level was equal to cost of the arches. In somewhat similar conditions in the Central Provinces reinforced concrete girder and encased steel girder slabs have proved very economical.

The calculations of thrust due to the velocity of river water in high floods (referred to in para. 15 (4) of the paper) would be of general interest if the author would kindly give them in his reply to the discussion on his paper. Such calculations are not given in ordinary text books on bridge design. The heavy, solid spandrels shown in the Parbati bridge design will cause a big afflux and offer great resistance to the river current so that the overturning moment will be very great in high flood.

Turning now to recent trends in design in the Central Provinces I would mention that the tendency now is to make the bridges wider than heretofore: in a long bridge it is considered that a 20 feet clear road way is the very minimum that should be provided for the safety and comfort of traffic. On the other hand considerable economies have been achieved by working to poorer mixes of cement concrete than those used on the Parbati bridge. For example, heartings of 1 : 5 : 8 plum cement concrete are common ; spandrel filling often consists of sand and shingle ; superstructure masonry is built in 1 : 6 cement mortar ; and plum concrete is used in all massive portions of the structure where ordinary concrete was previously used. In this connexion I was surprised to notice the low compression strengths obtained at the Parbati bridge for the cylinders of 1 : 2 : 4 cement concrete. Presumably the coarse aggregate was trap as trap rock was found in the excavation trenches The average compression strengths of 1 : 2 : 4 mix concrete (Swastika Indian cement)

in several bridges constructed in the Central Provinces as tested at Alipore were very much higher than those recorded for the Parbati bridge.

The type of collapsible railing shown was invented by Rai Bahadur Sunder Lal, Superintending Engineer, Public Works Department, Central Provinces. In the Central Provinces, however, in recent designs, raised copings have in many cases been omitted entirely or, where copings have been constructed, they have been made only 4½ inches high instead of 9 inches. The edges of the coping are always well rounded as it has been found that square edged copings are subject to damage in heavy floods. The grooves in the coping are provided with drainage vents to facilitate the removal of the silt which might be deposited in floods.

In the Central Provinces abutments are designed to be independent of any counter thrust from the earth fill behind as the fill is liable to be scoured out in exceptional floods.

It would be of interest to know whether the piers were strong enough in themselves to take the dead loads thrusts of the arches during concreting. In many cases it has been found that some bracing at this stage in the construction is necessary.

The type of expansion jointing described has not been used in submersible bridges in the Central Provinces. In fact, there are examples of bridges over 1000 feet long with no expansion joints at all except in the coping and paving and none of these bridges shows any signs of cracks. The actual temperature range in a masonry structure such as the Parbati bridge would appear to be much less than plus or minus 30° F. There is an interesting discussion on the subject on pages 237 and 238 of Vol. 239 of the Proceedings of the Institution of Civil Engineers, London (December 1934) in connexion with a paper read by Mr. A. W. H. Dean, then in the Central Provinces Public Works Department Service, on the construction of a submersible bridge over the Nerbudda River near Jubbulpore, Central Provinces. There may perhaps be some expansion and contraction of submersible bridges due to alternative wetting and drying during and after floods, but it is possible that in the case mentioned in the Central Provinces, the arches have been sufficiently flexible to dissipate the stresses caused by these variations.

So far, sand cushioning has not been used to any appreciable extent in the Central Provinces since lime concrete has been found to provide a good flexible cushion. In practice it has been found that the lime-concrete does not bind itself appreciably to the arch. When lime concrete is used the wearing surface of cement concrete paving can be reduced to 4½ inches, and even 3 inches has been adopted with success in some cases. Silicate of soda painting is regarded as of problematic value and is not now done in the Central Provinces.

The author is to be congratulated on a very interesting paper. The records of settlement of the arches on removal of the centerings, plastic deformation and deflections under loads are of particular value and the data recorded will be very useful to the future designer.

Mr. W. L. Murrell (Bihar) :—Mr. President and Gentlemen.—This paper has proved very interesting, and I would like, in consequence, to express gratitude to Rai Bahadur S. N. Bhaduri.

According to my rough calculations, with the flood standing at 48 feet above bed level, the profile of the masonry immersed amounts to about

20 per cent of the area of the hydraulic section of the river, as it stood before the construction of the bridge.

Considering the spandrel walls and the soffit of the arches as constituting the rightangled edge of an in-efficient orifice, and considering also the relatively high velocity of flow, it will be seen that the bridge presents an obstruction of well over 20 per cent and there will be a very considerable afflux.

Foundations for this project were easy and with very little risk of unequal settlement, so perhaps a structure of strong, slender, stream-lined, reinforced concrete piers on 70 to 90 feet centres and carrying steel pony-trusses or reinforced concrete cantilever beams would prove a satisfactory high level alternative design. It would be interesting to know whether such a scheme was considered and, if so, why it was not adopted.

Chairman :—I now call upon Rai Bahadur S. N. Bhaduri to reply.

Rai Bahadur S. N. Bhaduri :—As for Mr. McKelvie's general remarks I may say that the Parbati River overtops its banks almost every year during floods and as it would have been very expensive to build a high level bridge, it was decided to construct a submersible bridge and the designs were taken out accordingly. During construction it was found possible to raise the piers by 6 feet making the roadway just above the High Flood Level.

A comparative statement of cost with 80 feet span and with 103 feet span was actually taken out and the decision was in favour of 103 feet span. This was probably due to the fact that the Contractors (Messrs. Indian Patent Stone Co., Limited, Managing Agents—Messrs. Bird and Co., Calcutta) offered to construct 103 feet span arches at a lower cost, owing to their having the centerings for the larger span available from stock.

Reinforced Cement Concrete girders or encased steel girders should not in my opinion be used for submersible bridges because vibration is caused by flood water passing in contact with the girders. Of course a bottom decking would remove this objection but then the cost would be increased.

A reference to the calculations for the stability of the bridge against horizontal force caused by the velocity of water will show that the co-efficient of friction *i.e.*, $\frac{\text{Total force}}{\text{The weight resisting horizontal force}}$ is only .146. And this is quite safe.

The question of making a wider bridge across the Parbati River was considered at the time of designing the bridge and it was found that there was no possibility of getting a larger amount sanctioned by either the Government of India or the Gwalior Durbar, and therefore it had to be given up.

In all mass concrete work 15 per cent plums were used.

I shall be glad if Mr. McKelvie will send me the details of test results of the Central Provinces bridges and the materials and the mixture used so that the matter may be investigated. Crushing strength of 3192 to 4000 pounds per square inch with trap stone as coarse aggregate is considered good.

The coping was specially made 9 inches high with the object of providing a wheel-guard all along the roadway to prevent wheels of bullock-carts from knocking against the railings. The edges of the copings are well rounded and outlets are provided for drainage.

In designing the abutments the counter thrust of earth backing has been ignored as will be seen by a reference to the calculations. Slip joints have been provided at the end between the abutment and the wings.

As the centering on adjacent spans were put up simultaneously, the piers were not braced separately during construction of arches.

We have found cushioning with sand of advantage and have done so in all reinforced cement concrete bridges of 24 feet span.

Silicate of soda was used as an experimental measure to see how the surface concrete behaves with its application.

On 24 feet span reinforced cement concrete bridges Silicate of Soda was not used.

Mr. McKelvie has not mentioned the spans of the Central Provinces bridges. For arch bridges of 100 feet span or more expansion joints are in my opinion necessary.

As for Mr. Murrell's remark it may be pointed out that for a submersible bridge the question of afflux does not arise to the same extent as for a high level bridge. A comparative statement of cost of a bridge with 80 feet span and one with 103 feet span was prepared and as the latter proved cheaper, it was adopted.

It must be remembered that the Parbati bridge was designed as a submersible one and therefore pony trusses or cantilever beams were ruled out of consideration owing to the difficulty of anchoring; these properly against the uplifting and thrusting forces of flood water.

Chairman :—Gentlemen—I am sure we must all feel very grateful to Rai Bahadur Bhaduri for giving us such a careful description of an important work actually carried out and I would strongly urge members of this Congress to give us more papers like it.

A most valuable feature of the paper is the detailed itemised statement of cost. This information is often omitted or supplied in highly summarised form and I would draw the attention of Members who propose submitting papers of this nature to the great value to the profession at large and our Members in particular of these detailed cost statements.

In inviting Members to give us more papers of this kind I would ask them to include the following particulars :—

1. A dimensioned cross section of the roadway.
2. The loadings on which the design is based.
3. The cost per square foot of the elevation area comprised by the road level and the bottom of the foundations.
4. The ratio of the total cost of the substructure to the cost of those parts of the superstructure as are subject to variation with variations of span.

I would urge the Congress to secure information regarding these items for all types of bridges for which it is available to its members and to send them to the Secretary, since a collection of exact information on these points will be, if sufficiently extensive, of the highest value.

APPENDIX I.

TOURS AND OTHER FUNCTIONS HELD DURING THE THIRD INDIAN ROADS CONGRESS, LUCKNOW, FEBRUARY 1937.

Thursday, February 18, 1937.

The delegates assembled at the Hardinge Library, Queen's Gardens, Delhi, and proceeded from there in buses to inspect the following items on the Grand Trunk Road.

(1) DELHI PROVINCE.

Note.—(*a*). *Brief constructional specifications of items to be inspected are given in Appendix A.*

(*b*). *References relate to the Proceedings of the Inaugural Indian Roads Congress. Mile 1 Meerut Road means Mile 884 G.T. Road, Mile 2 Meerut Road means Mile 883 G.T. Road, and so on.*

(1) CEMENT CONCRETE ROAD—2 Furlongs. (page 37 of Proceedings).

PRESENT CONDITION.

An examination of the surface of this road shows that it is being eroded under the weight of traffic. The erosion, in a number of slabs, is as much as three quarters of an inch in short lengths—The construction joint has widened being about 3 inches wide now and at the ends of the slabs at the transverse joints dish-like hollows have formed.

(2). 2½ INCH PREMIXED COAT WITH HOT SOCONY ASPHALT—Laid in furlongs 2 and 3 of Mile 884 G.T. Road (page 46 of Proceedings).

PRESENT CONDITION.

It has been necessary to repair this with a number of patches, and the surface also shows corrugations.

(3). GROUTING WITH HOT ASPHALTS—(Page 22 of Proceedings).

(i). *2 inch Grouting with Mexphalte and a Seal Coat.*

PRESENT CONDITION.

The surface bleeds in the hot sun causing the bitumen to creep towards the edges where it may be seen collecting along the brick edging.

Several patches have been necessary where the surface began to disintegrate as a result of some of the bitumen content being squeezed out under the weight of the traffic.

Corrugations have also formed in some short lengths. It would appear there was an excess of bitumen in this work.

(ii) *2 inch Grouting with Socony Asphalt and a Seal Coat.*

PRESENT CONDITION.

Several patches have been noticed where the surface has disintegrated. The bitumen in these patches appears to be less plastic and hence the carpet is more rigid than the Mexphalte grout. The surface does not bleed and has no corrugations.

(4). $2\frac{1}{2}$ INCH SHELCRETE—(4th and 5th Furlongs of Mile 882 G.T. Road. (page 24 of proceedings).

PRESENT CONDITION.

The surface shows marked depressions some of which have been levelled up by the maintenance staff by filling them with premixed stone grit. This has made the surface rather bumpy.

A few patches have been noticed where the surface has disintegrated.

(5). $2\frac{1}{2}$ INCH TRINIMAC—(Furlong 3rd of Mile 882 G.T. Road. (page 47 of the proceedings).

PRESENT CONDITION.

The wearing surface is breaking up at the edges. In a few places where patches were necessary the binder course was found to have moved. This led to disintegration of the structure.

There is little adhesion between the wearing and the binder courses in this specification. Corrugations are also found.

(6). PAINTING WITH SPRAMEX DOUBLE COAT.—(Mile 881 and 2 furlongs of Mile 882).

This section of road affords a good example of how a surfaced road which has deteriorated can be improved without having to remetal it.

This work was done two years ago and the surface to-day is quite intact and is standing up well.

The road was remetalled in the year 1930 and was first painted with Trinimac Asphalt Cement in the year 1930-31. It was re-painted in the year 1931-32.

During the winter of the year 1935 the bitumen lost much of its ductility, as a result of frost It disintegrated under light tapping and on this account it came off in patches faster than the rate at which two maintenance road gangs could do the necessary patching. Despite all the labour and materials thus spent on it the surface became bumpy and broke up still faster.

The metalled surface was, however, hard and intact and therefore, it was decided to scrape off the whole of the old painting coat and apyly a double coat of paint after levelling up pot-holes and loose spots.

The stone grit used with the first coat was $\frac{3}{4}$ inch to $\frac{1}{2}$ inch gauge and that with the second coat $\frac{1}{2}$ inch to 1/8 inch—a total of 5 cubic feet per 100 square feet was used. The bitumen used was Spramex 80/100 at the rate of 5 gallons per 100 square feet for the two coats.

The cost of the work inclusive of the cost of scraping was Rs. 5/7/- per hundred square feet.

(II). UNITED PROVINCES.

Grand Trunk Road (*Continued*).

(1). MILE 879

This mile is similar in construction to item (2) being done at the same time. When the unevenness first became bad in 1934 an effort was made to rectify it by giving two coats of paint. The first was applied to the low spots with the object of bringing them up as much as possible. The second coat was given over the whole surface. Though this improved matters to some extent the surface will still be seen to be very uneven. The road is 16 feet wide and carries a traffic of 1184 tons.

(2). MILE 878.

This mile was one of the earliest attempt at asphalt road construction in the United Provinces having been constructed in 1926. It is asphaltic concrete, 3 inches thick, the bitumen being Trinidad Refined Asphalt and Flux Oil. The road is 16 feet wide and carries a total traffic of 1184 tons per 24 hours. The surface gradually became very wavy and by March 1934 was so bad that travelling over it at a speed of more than 25 miles per hour was difficult. This defect was attributed to the use of too large a proportion of bitumen in the mixture. Efforts were made to improve the evenness of the surface by repainting. They were to some extent successful as the surface was at one time far worse than it is now. It will be noticed that, apart from the unevenness, the road has stood the traffic well. Cost Rs. 5, 3/7 per square yard.

(3). MILE 872 (FURLONG 6).

The object of interest here is the peculiar behaviour of one bay of this concrete road. The slab is $5\frac{1}{2}$ inches: $3\frac{1}{2}$ inches: $5\frac{1}{2}$ inches made with rapid hardening cement to a mixture of 1:2:4.

The bay in question was laid on March 26, 1935, and was opened to traffic 30 days later. On June 14, 1936, a piece about $1\frac{1}{2}$ feet in diameter exploded with a loud report like that of gun fire, the bay cracked transversely and a number of small cracks also appeared. The cause of the explosion could not be determined definitely. It was thought however, that it may have been due to some portions of the rapid hardening cement having been left unmixed in the mixture and they might have got damp after the rains. Perhaps delegates may be able to offer a suggestion. The mile is 12 feet wide and carries 622 tons.

(4). MILE 866.

This mile was painted with a coat of Shalimar Tar No. 1 in June 1935, and then with Spramex in October, 1935. It is one of the five miles on this road that were painted before it was decided to adopt cement concrete. The traffic is 622 tons on a width of 12 feet. It will be seen that in places patches are beginning to form and the paint appears to be peeling off.

(5). MILE 865.

This concrete mile was completed in November 1935. The slab is $5\frac{1}{2}$ inches: $3\frac{1}{2}$ inches: $5\frac{1}{2}$ inches and the mixture 1:2:4. About one month after the mile had been opened to traffic hair cracks were noticed in some bays. For about three months they gradually extended until they became about 4 feet long after which the extension ceased. Most of the cracks are about 2 feet from the edge

of the road and it is thought that they may have been due to lorries passing over the bays when they were only partially cured. This 12 feet mile carries 622 tons.

(6). MILE 857 (FURLONGS 4 & 5).

The concrete road slab here is $5\frac{1}{2}$ inches: $3\frac{1}{2}$ inches: $5\frac{1}{2}$ inches and mixture 1:2:4. The point of interest is that the road has been constructed in two lots. In the one-half the alternate bay method of construction was adopted, the bays being 33 feet long. On the other side of the road the continuous bay method was adopted and a length of 165 feet was completed as one bay. In other respects the two lots of the road are the same. It will be noted that transverse cracks have appeared at a distance apart which is less than 33 feet. Beyond these transverse cracks no defects have come to light. Traffic is 622 tons over 12 feet wide road.

(7). MILE 848 (FURLONG 5).

This concrete road was opened to traffic in May 1936. In order to see the result of the work a slab, 4 feet in length, was cut out of the road surface after it had been under traffic for about four months. This slab is to be seen. The road is 12 feet wide and carries 496 tons.

(8). MILE 847 (FURLONGS 4-8).

In this mile an experiment is being made to determine the difference in behaviour, if any, between a silicated and unsilicated surface. The even bays were silicated with three coats in the usual manner soon after laying. A white cross has been put on the corner of these bays. The odd bays have not been silicated. The road was opened to traffic on December 30, 1936. Traffic is 496 tons on a width of 12 feet.

The party reached Bulandshahr at about 2 p.m. and after taking lunch at the railway station left in a special train reaching Cawnpore at mid-night.

Friday, February 19, 1937.

The party re-assembled at the Cawnpore Railway Station and proceeded from there in cars to inspect the following items.

GRAND TRUNK ROAD.

(1). MILE 620 (FURLONGS 1-$3\frac{1}{2}$).

A thin concrete slab is being laid here on an existing water-bound road, the surface of which had been previously painted but which had failed to stand up to the traffic which is according to census, 4250 tons on the full 24 feet width of the road. The road slab is 3 inches: 2 inches: 3 inches and is being constructed in two strips each 10 feet wide with a central contraction joint. The mixture of the concrete is 1:2:4 and it is being reinforced with a 6 inch mesh of $\frac{1}{8}$ inch diameter steel wire. It will be noted that in the preparation of sub-grade there is no insulation layer. On the contrary a cement wash is being given to provide adhesion. The surface is not being treated in any way except for one or two experimental bays.

This work is being done as the result of the very satisfactory results that have been obtained from a trial length of 200 feet laid in January, 1935, under a traffic of 900 tons. This is item (13) and was inspected later in the day.

(2). MILE 620 (FURLONGS $3\frac{1}{2}$—8).

The road slab here is 20 feet wide and has been laid in two strips of 10 feet each with a central contraction joint. Each slab is 6 inches : 4 inches : 6 inches of a 1 : 2 : 4 mixture and is not reinforced. The surface has been hardened with silicate of soda. The recorded traffic figure here is 4250 tons per 24 hours on the 20 feet width. The work was completed in March, 1936, so that it has now been under traffic for 11 months.

(3). MILE 621.

This mile is a fair example of the grouted work put down in the early days of road reconstruction. At the time, it was believed that such a construction would be capable of satisfactorily taking the traffic. The squeezing effect of heavily loaded iron tyres was unsuspected. In this particular mile the bitumen used was Trinidad Refined Asphalt and Flux Oil. The work was done in 1929 and the traffic is 2850 tons per 24 hours. The failure is typical. The work was expensive (Rs. 3 7/- per square yard in this case) and, as has been since proved, the results did not justify the outlay.

In order to show the manner in which the grout coat has squeezed it has been cut off from one-half of the road. The section exposed may be of interest.

(4). MILES 622 and 623.

These two miles are of similar construction to that in item (3) but in this case the materials used were Mexphalte and Spramex, a comparison can, therefore, be made with item (3). The work was done in 1928-29 and the traffic it has to stand is 1800 tons per 24 hours on the 16 feet width. These miles will shortly be replaced by concrete. The existing grout cost about Rs. 3/2/- per square yard. At the present day a 6 inches : 4 inches : 6 inches concrete slab could be put down for the same money and it seems likely that such a slab would stand the traffic satisfactorily.

(5). MILE 624 (FURLONGS 1-4).

This was Trinidad Refined Asphalt semi-grout laid in March 1929. It will be seen that the road has completely broken up. The traffic here is 1650 tons on the 16 feet width and it is evident that the form of construction is not suited to the load it has to take. It may be mentioned that the surface was repainted in 1934. This section is being replaced by a thin slab of Reinforced cement concrete.

(6). MILE 624 (FURLONGS 5-8).

This section was grouted with Trinidad Refined Asphalt in June 1929. It is interesting to note how this has completely broken whereas item no. (3) which is of a similar construction has only been rutted. The traffic is about the same and no explanation can be offered for the difference in behaviour. This section is being replaced by a thin slab of reinforced cement concrete.

(7). MILES 625 To 629.

These are of no special interest but as it is necessary to pass over them it may be mentioned that they have received surface treatment of different kinds.

Mile 625 is Spramex. Last painted in May 1935.

Mile 626 is Spramex and was last painted in June 1936.

(These miles are 16 feet wide and carry a traffic of 1250 tons).

Mile 627} These have a single coat of Tar
Mile 628} given in May 1936.

Mile 629 is Spramex over ORMUL emulsion and was last painted in November 1933.

(These three miles are 12 feet wide and carry a traffic of 987 tons).

(8). MILE 630.

This is an instance of a mile with a bitumen painted surface being unable to stand up to a traffic of about 987 tons per 24 hours on a 12 feet width. The original coat of paint was given in 1929 and it was last painted in July 1934. The old surface is now being replaced with a thin concrete slab. This new work is experimental in character. Each furlong will be treated slightly differently. Work should be actually in progress at the time of the visit. The mixture in each case is 1:2:4 and it is intended that:—

Furlong 1 shall have a 3 inches : 2 inches : 3 inches slab.

Furlong 2 shall have a slab of 2 inches uniform thickness.

Furlong 3 shall have a 3 inches : 2 inches : 3 inches slab reinforced with a 4 inches mesh of 1/8 inch diameter steel wire.

Furlong 4 shall be of 2 inches uniform thickness with reinforcement as in furlong 3.

Furlong 5 shall have a 3 inches : 2 inches : 3 inches slab reinforced with rabbit netting.

Furlong 6 shall be of 2 inches uniform thickness reinforced as in furlong 5.

Furlong 7 shall have a 3 inches : 2 inches : 3 inches slab un-reinforced.

Furlong 8 shall have a 2 inches uniformly thick slab and will be un-reinforced.

These all were carefully watched for comparative purposes.

LUCKNOW-JHANSI ROAD.

(9). MILE 51 (FURLONG 4) TO MILE 52 (FURLONG 5).

This road is 24 feet wide and shows how Asphaltic cement concrete has failed under exceptionally heavy mixed traffic amounting to no less than 3,370 tons. The road was constructed in 1926 and no surface treatment has been given since it was constructed. The roadway will be replaced by one of cement concrete. This section may be compared with item No. (10) below.

(10). MILE 52 (FURLONG 6—8).

This cement concrete road, which was constructed early in 1929, may be compared with item No. (9), the width and traffic being the same, *i. e.*, 24 feet wide and has been constructed in two strips with a centre joint. Each strip is 8 inches : 6 inches : 7 inches and the contraction joints are at an angle of 60 degrees with the centre line. The surface treatment consisted of hardening with Silicate of Soda. The cost of construction was high, being Rs. 6/2/- per square yard but the work was done when the cost of cement was high. It should be noted that the thickened edge at the centre joint necessitates the forming of the subgrade to a section which cannot be consolidated with a steam roller. Hand ramming has to be resorted to, the same degree of compaction is not obtained, and it is possible that this may be a source of weakness,

(11). MILE 55.

This mile was painted with Trinidad Refined Asphalt in March 1930. It was again painted with Spramex in April 1933, and again in May 1935. This mile has broken up and is to be replaced with concrete eventually. The mile is 16 feet wide and carries a traffic of 879 tons.

(12). MILE 56 (FURLONG 3, FIRST 460 FEET).

In this length an experiment was tried by forming the concrete road slab in two layers, the bottom layer being of a cheaper material and the top layer of a more durable one. The under layer of concrete was made with brick ballast and sand to a mixture of 1 : 8 : 16 and laid to a section of 4 inches : 3 inches : 4 inches. The upper layer was made with stone ballast to a 1 : 2 : 4 mixture and laid to a section of 3 inches : 2 inches : 3 inches, thus making a 7 inches : 5 inches : 7 inches composite slab. The cost worked out at Rs. 3/- per square yard. As a straightforward slab of a section of 5½ inches : 3½ inches : 5½ inches can be constructed for the same cost, there appears to be little advantage to be gained by adopting the more complicated construction. This mile is 12 feet wide and carries 879 tons.

(13). MILE 56 (FURLONG 3, LAST 200 FEET).

This is an example of a thin concrete road. The section of the slab is 3 inches : 2 inches : 3 inches only, the mixture being 1 : 2½ : 4 and reinforced with 1/8 inch round iron laid in a 6 inches mesh. There is no insulating layer under the slab. It is laid directly on the stone sub-grade after cleaning the latter and giving it a cement wash. The road was constructed in January 1935, carries about 900 tons of mixed traffic per 24 hours, and is wearing very satisfactorily. Encouraged by these results thin slabs are being experimented with under heavier traffic, vide items (1), (5), (6) and (8). The traffic in this mile is 879 tons on a width of 12 feet. It may be again noted here that in item (1) this construction is being tried on a 24 feet road carrying 4250 tons. On the half width this may be taken as 2125 tons or about 2½ times the load carried by this road.

LUNCH INTERVAL.

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(14). MILE 45.

Cement concrete 9 inches : 6 inches : 9 inches in section was laid in 1931. Prior to this the road was kankar which used to last not more than a year. The traffic amounts to about 2200 tons per 24 hours and consists largely of bullock carts. The concrete pavement is 20 feet wide without any central joint. An insulation layer of sand was provided under the concrete and the surface of the latter was treated with silicate of soda on completion. Except for occasional filling of the joints with Bitumen there has been practically no expenditure on maintenance. This mile is an example of a fairly old length of concrete, of the thickness originally adopted, which is behaving normally.

(15). MILE 45 (BRIDGE IN FURLONG 8).

At this point the concrete slab is of interest because the roadway over the bridge was laid in one continuous slab 109 feet long and 18½ feet wide, and 6 inches thick throughout. The edges were not thickened. In spite of the unusually large size and the inevitable vibration caused by the bridge there has been no appreciable cracking.

(16). MILE 40.

This mile was constructed in 1929 and was one of the first miles laid by the staff of the Lucknow division. The mile is of interest as showing the marked degree of waviness, causing uncomfortable travelling, which can result from lack of care and knowledge in laying the concrete. It is believed that this waviness is chiefly due to lack of attention in bedding the side forms firmly, seeing that they are correctly levelled and ensuring that the concrete on either side of joints is perfectly true to level. The general design etc. of the concrete was the same as in the miles already seen.

(17). MILE 38, (FURLONGS 1-4).

The road is Trinidad Refined Asphalt grout laid in 1928 over water-bound stone done in 1927. The thickness of the grouted coat was 3 inches. The traffic is not more than 1000 to 1100 tons per 24 hours. The mile has not stood well; ruts appeared first and then the whole surface became uneven. The mile will shortly be surfaced with concrete 3½ inches thick.

(18). MILE 37.

In this mile there are two test lengths of Tar/Kankar premix and Tar/Stone premix, laid under the direct control of the Shalimar Tar Co. The Tar/Kankar premix was purely experimental and was not guaranteed by the Company. The traffic in this section amounts to over 1000 tons per 24 hours. The mile was painted in 1927 but in the following five years had to be painted three times; even then the surface was poor.

The two tar carpets have been under traffic for over 18 months and the stone carpet is still in good condition though the kankar carpet is showing wear and is developing slight ruts.

(19). MILE 36.

Four furlongs of this mile have been used as an experiment with "GUNITE" with the object of ascertaining whether this method of applying concrete is likely to be successful on (a) water-bound stone, (b) water-bound kankar and (c) concrete. There are many variations in the specification of the Gunite in regard to thickness, reinforcement etc. Six inch mesh light B. R. C. reinforcement was used in a few bays; the thickness of the Gunite was 1 inch in some places and 1½ inches in others and the mixture was 1 to 3½ in the greater part of the road and 1 to 4 in the remainder. The surface shows many cracks but these are considerably more noticeable in the unreinforced lengths than in the others. One bay was made of a length equivalent to the day's work *i.e.*, 260 feet long; in this bay the cracks are more numerous than elsewhere.

As the work was only completed in November last it is too early to arrive at any final conclusion. The firm concerned, Messrs. John Fleming & Co. have been sufficiently interested by this experiment to carry out more work in Bombay.

The delegates reached Lucknow in the evening.

SATURDAY, FEBRUARY 20, 1937.

(Forenoon).

The party re-assembled at the Council Hall, Lucknow at 9 a. m. and proceeded from there in buses to inspect the following items around Lucknow.

(20). MILE 8.

The mile is surfaced with brick ballast surface painted. The work was done in 1931. Bitumen emulsion was used for the first coat and there have been two repaints since that year but the mile is standing up well. Prior to 1931 the mile was of water-bound kankar but this failed to last more than two years although the volume of traffic is not more than 700 tons.

(21). MILE 5.

The traffic in this mile was last counted as somewhat over 1000 tons per day but the increase of brick kilns has probably raised the tonnage to nearer 2000 tons. This length of Shellcrete was one of several experimental lengths laid in 1931, the other lengths having already been removed. This Shellcrete was laid under the supervision of the company.

(22). MILE 3.

The mile carries about 100 tons of traffic per day much of which consists of heavily laden bullock carts from the goods shed. The point of interest is the concrete side strips with asphaltic concrete between In 1927 asphaltic concrete (Trinidad Refined Asphalt) was laid over the whole width. Very soon it developed ruts at the sides and maintenance was heavy. In 1930 the asphaltic concrete was removed from one side and cement concrete 6 inches thick and 9 feet wide was laid for the heavy incoming traffic It will be seen that under very heavy traffic which "tracks" badly this concrete has worn in places: this is partly attributed to bad drainage and, perhaps, inherent weakness at the joints.

Another point of interest in this mile is the rough portion which was passed near the under-bridge. Here the asphaltic concrete on the slope became very uneven and in 1934 was dug up and, after breaking up and adding a small percentage of asphalt, relaid. The surface was improved for some time but it has again become very rough and will shortly be replaced by stone setts. Stone setts are being adopted instead of concrete as bullocks dislike the latter on the fairly down grade and endeavour to get on to a surface which offers more tractive resistance.

(23). MILE 2.

The surface of this mile is 3 inch Asphaltic concrete laid in 1926. This volume of traffic is about 2000 tons but much of this is concentrated on the incoming side. The surface, particularly on this side, is very rough and frequent repairs are necessary.

LUCKNOW-BENARES ROAD.

(24). MILE 2.

This mile is a good example showing the great difference in wear caused to a painted road by (a) rubber tyred traffic and (b) bullock carts. The total volume of traffic on the mile is about 4000 tons per day of which about 3000 consists of motors and rubber tyred tongas and the balance of bullock carts. It will be seen that the side on which laden carts enter the town the surface is

APPENDIX A.

BRIEF SPECIFICATIONS.

FOR ITEMS INSPECTED IN DELHI PROVINCE.

CEMENT CONCRETE ROAD.

For the concrete road a section 7 inches: 5 inches: 7 inches has been adopted with a central construction joint and an expansion joint at 33 feet intervals. A few bays have been constructed of the full width with straight and skew joints.

Two long bays of the full width of cross section have been constructed with an expansion joint only at the end of each day's work Hoop iron hexagonal rings have been introduced $1\frac{1}{2}$ inches below the finished surface. It is expected that fine contraction cracks will occur following these hexagons and large cracks will be avoided. Edge reinforcement and M. S. dowels have been given in certain slabs.

MATERIALS.

Cement:—The cement used is slow setting Portland cement of B B B brand manufactured by Bundi Portland Cement Ltd. It passed the following tensile tests made by the manufacturers with standard sand:—

Sand and Cement Ratio 3 to 1.

After 3 days	...	...	421 lbs. per square inch.
After 7 days	...	...	517 do.

The cement was supplied in jute bags and a certificate was furnished by the manufacturers showing that each consignment was tested and that it conformed in all respects to the British Standard Specification for Portland cement.

The tensile tests made of each consignment on its delivery at the site of work gave the following results:—

Budya Nala Sand and Cement Ratio 3: 1

After 3 days	...	...	341 pounds per square inch.
After 7 days	...	...	426 do

The quantity of cement used was 635 pounds per cubic yard of finished concrete.

$2\frac{1}{2}$ INCH PREMIXED COAT WITH HOT SOCONY ASPHALT.

Materials:—Bitumen. Hot Asphalt grade 101 of Standard Vacuum Oil Co., with a cut back.

Aggregate:—For binder coat. $1\frac{1}{2}$ inch to 1 inch stone metal.

For Wearing coat. $\frac{3}{4}$ inch to $\frac{1}{2}$ inch stone grit.

Preparation of Base:—This section of the road has been given a coat of two inches metal grouted with Colfix Emulsion in the year 1932-33 which soon

after laying showed signs of deterioration and gave way under the weight of intensive brick cart traffic which this section carries. It was in such bad order as to necessitate complete removal before laying the premixed coat. The base, after removal of the grouted layer showed many loose spots which were picked out. Prior to laying the premixed coat they were carefully filled up with premixed aggregate, levelled up and rolled so as to form a hard base.

Preparation of Premix:—The Asphalt (Socony 101) was heated in a tar boiler to 350°F and the correct quantity at the rate of 3 pounds per cubic feet of stone metal was drawn off from it into a bucket. To this was added a cut back Socosol, at the rate of 1 ounce to every 1 pound of Asphalt.

The cut back was made by mixing Socony Asphalt 105 of 80-100 penetration and Kerosene oil. The Asphalt was heated to 250°F in a tar boiler and was drawn off into a container in which it was mixed with Kerosene oil in equal quantities by volume.

The aggregate was mixed in locally made drum mixers mounted on a wooden frame work. Each mixing drum had three mixing arms fixed inside which prevented the aggregate from sticking together.

The mixture of Hot Asphalt and Socosol 6 pounds weight was poured over the 2 cubic feet of stone metal in the drum which was then rotated by two men 150 times, after which the premixed material was taken out and carted in wheel-barrows to the site of work.

Construction:—

Binder coat:—The premix was evenly spread on the road to an uncompacted depth of 2 inches and rolled by a steam roller till no movement took place.

Wearing coat:—Stone chippings ¾ inch to ⅓ inch size mixed with fine dust in equal proportions were premixed in the same manner as described above and spread on the binder course to an uncompacted depth of 1 inch and consolidated.

Fine stone dust was then spread on the surface and the road opened to traffic.

Cost:—Rs. 17-8-0 per hundred square feet.

GROUTING WITH HOT ASPHALTS.

Before spreading the metal, the road surface is cleaned of all foreign matter. The metal used is 1½ inch to 3/4 inch gauge, clean, dry and free from clay or dust and uniformly spread to the correct depth. The loose metal is half an inch more in thickness than the finished coat, *i.e.*, for a 2 inch coat metal is spread 2½ inch thick.

The old surface of the road is first picked up and relaid to correct camber and grade. The stone metal is not dumped on the road surface but to ensure uniformity of spreading is stacked at the road side. Irregularities in spreading are carefully looked for and corrected by hand packing. Templates are used at short intervals with strings stretched between them as a guide. This is all done before rolling, as it is difficult later on to correct irregularities and experience has shown that unevenness of surface and weak spots are mainly due to uneven spreading. A ten ton roller is used on the dry metal. Rolling is commenced at the sides and advance towards the centre by successive stages of at least half the width of the roller until the surface is uniform and compact.

During the winter months bitumen (Mexphalte 30/40) does not penetrate into the interstices more than an inch owing to the quick fall in its temperature on coming in contact with stone metal. This difficulty is overcome by spreading the metal for a 2 inch coat in two layers of 1¼ inch each. Half the quantity of bitumen is used in each layer. Rolling is started as soon as the second layer has been grouted and the chippings have been spread.

HOT BITUMEN ASPHALTIC CONCRETE (SHELCRETE AND SHELSHEET).

The bituminous materials in this case were Mexphalte 20/30 penetration and "Shelmac" a "cut back" made by the Shell Company with bitumen and Solar oil. A "cut back" of this type is relatively simple to manipulate and easy to work. It needs only slight heating and the mixed aggregate can be laid either cold or hot immediately or be stored. If after some time it gets hard, it can be softened by the addition of a little Solar oil.

The grading of the aggregate was varied according to the thickness of the coat. For 1 inch Shelsheet the stone was of ¾ inch to ¼ inch gauge and for thicknesses of 2 and 2½ inch of 1½ inch to ½ inch gauge. Sand containing 9 per cent coarse (−2 mm+.6 mm), 80 per cent medium (−.6 mm+0·2 mm), 6 per cent fine (−0.2 mm+·085 mm), and 5 per cent dust (−·085 mm) was used. In damp or cold weather the sand was heated to about 110°F on iron sheets six inches above ground level with a fire underneath.

For a 2½ inch finished coat (shelcrete) batches of 3 cubic feet of stone metal of 1½ inch to ¼ inch gauge and 1½ cubic feet sand were used with 22½ pounds of the mixture of Mexphalte and Shelmac. The surface of the road was first brought to the proper camber and grade and all potholes were filled in stone metal coated with bitumen without sand being found very satisfactory for this.

2½ inch thick Shelcrete was laid for heavy cart traffic, and 1 inch Shelsheet for lighter traffic. No expenditure has been incurred in the maintenance of the shelcrete but some patching has been necessary with the Shelsheet.

SPECIFICATION FOR 2½ INCHES TRINIMAC.

Material:—Trinimac Asphalt cement is prepared by mixing Trinidad Lake Asphalt and flux oil by taking 80 parts of the former and 20 of the latter. The flux oil is a residual product of Petroleum distillation and should have a flash point of 400°F.

To prepare the Asphalt cement, the Lake Asphalt is heated in a tar boiler to a temperature of 250°F and the flux oil is gradually added, the contents being thoroughly stirred so as to ensure complete incorporation of the asphalt with the flux oil.

Aggregate:—For binder course 2 inches to ½ inch.

Wearing surface ½ inch to dust.

General Remark:—This section of the road was treated with Premixed course of Socony Emulsion varying from 1 inch to 3 inches in thickness. The surface, however, soon after that treatment disintegrated and it became necessary to remove it completely before laying the Trinimac.

Construction:—

Binder Course:—The Trinimac Asphalt cement prepared as above was heated to a temperature of 350°F in a tar boiler, and drawn off into a bucket

and mixed with aggregate in a rotary mixer, the stone aggregate being at atmospheric temperature.

4.8 pounds of Asphalt cement were required per cubic foot of stone aggregate to completely coat every particle of it. As soon as mixing was complete the Trinimac was taken out of the mixer and carried to the site of work, where it was stacked and used cold. It was evenly spread on the prepared base to an uncompacted thickness of 2½ inches. It was then rolled to complete consolidation with a steam road roller.

Wearing Surface:—The proportion of aggregate to asphalt cement was the same as in the Binder Course. The wearing surface was spread immediately after the consolidation of the binder course aud was rolled to final consolidation. The total compacted thickness of the two courses was 2½ inches. The finished surface was then dusted over with stone dust and a final rolling given before opening the road to traffic.

Cost:—Rs. 22-4 per 100 sq. ft.

Saturday, February 20, 1937.
(afternoon)

The delegates assembled at the Council Hall, Lucknow, to witness the following demonstrations which had been arranged there:—

(1) Solex Governor Carburetar arranged by Messrs. Rane Limited,

(2) Avery Portable Wheel Weighing Machine arranged by Messrs. W. & T. Avery Limited, Calcutta, and

(3) Bullock carts arranged by the Local Public Works Department.

Monday, February 22, 1937.
(afternoon)

The Council entertained all delegates and their families and certain local distinguished guests at a tea party given at the Municipal Hall, Lucknow, at 4 p.m.

APPENDIX II.

INDIAN ROADS CONGRESS STANDARD SPECIFICATION AND CODES OF PRACTICE FOR ROAD BRIDGES IN INDIA.

The following correspondence and notes are published in order to provide an answer which can easily be referred to when criticisms of the "Indian Roads Congress Standard specification and Codes of Practice for Road Bridges in India". crop up. Mr. W.A. Radice's notes will explain the general basis on which the above named publication has been drawn up.

Letter from Mr. W.A. Radice of the Braithwaite Burn and Jessop Construction Company, Limited, Calcutta, dated the 20th July 1936, to the Secretary, Indian Roads Congress.

Proposed Standard Indian Road Bridge Specification.

I have the honour to forward herewith :—

(a) A Note on Standard Loadings and impact.

(b) The proposed Standard Indian Road bridge specification (Published as a separate publication called "Indian Roads Congress Standard Specification and Codes of Practice for Road Bridges in India).

The note describes the considerations which have led me in my choice of the standard loadings and impact factor put forward in the proposed standard specification.

2. Mr. W. J. Turnbull of the Concrete Association of India has contributed Section D of the proposed standard specification dealing with Reinforced Concrete Bridges. This is based on the Indian Railway Standard Code of Practice for Reinforced Concrete, Construction adopted in 1936 which, in its turn, is largely based on the Code of Practice for the Use of Reinforced Concrete in Buildings published by the (Imperial) Department of Scientific and Industrial Research.

3. The note on standard loadings and impact and the whole of sections A and B of the proposed standard specification (General and Loads and Stresses sections) which govern both Section C—Steel Bridges and Section D—Reinforced Concrete Bridges was sent to Mr. W. J. Turnbull under my letter No. A/729 of the 12th June and a copy of his reply No. R/47/11031 of the 7th July 1936 and its enclosures (reproduced below).

4. Mr. W. J. Turnbull, whilst assenting to the proposed standard loadings without qualification, desires to put before the Main Committee (Bridge Loading and Permissible Stresses Sub-Committee of the Indian Roads Congress) my note as it stands but accompanied by certain references indicating that the impact factor for certain types of reinforced concrete road bridges might be lower than the impact factor adopted for steel bridges.

5. After the main conclusions put forward in my note on standard loadings and impact had been arrived at I received your letter No. C 85 dated the 26th May 1936 which, amongst other very valuable information, also supplied me with the opinions of Chief Engineers etc., on the proposals for standard bridge loadings made by the Road Engineer in his letter No. C 21 dated 14th May 1932.

6. As I desire to comment on expressions of opinion referred to in paragraphs 4 and 5 above, I have also appended to this letter a Supplementary Note (reproduced below) on Standard loadings and Impact for the consideration of the Bridge Loading and Permissible Stresses Sub-Committee of the Indian Roads Congress.

7. It only remains to deal with Mr. W. J. Turnbull's reference to the weight of reinforced concrete made in his letter No. R/47/11031 of the 7th July 1936 where he considers that the weight of a cubic foot of reinforced concrete, as generally accepted, is 150 pounds and not 160 pounds as given in Clauses B 2 and D 15 of the proposed standard specification. This is a matter which comes under Mr. Turnbull's terms of reference and therefore my remarks are as from the draughtsman of the B section of the proposed standard specification The weight of 160 pounds for one cubic foot of reinforced concrete is given in Clause 15 of Section V of the copy of the Indian Railway Standard Code of Practice for Reinforced Concrete Construction forwarded to me by Mr. Turnbull himself and of which Section D of the proposed standard specification is an exact copy.

8. On behalf of Mr. Turnbull and of myself the above papers etc., are forwarded to you in discharge of the duties laid upon us by the Council of the Congress by their resolution recorded under No. 6 of the minutes of the meeting of the Council of the Indian Roads Congress held at Bangalore on the 11th January, 1936.

Note on Standard Loadings and Impact.

by Mr. W. A. Radice.

Historical:—In 1931 the Committee of Chief Engineers of the Road Conference considered the question of standard loadings for road bridges and they came to the following conclusions :—

1. That there is really only one general road classification viz. roads which at present carry, or may in course of time be expected to carry motor transport. The exceptions being :—
   (*a*) special localities such as industrial areas.
   (*b*) other localities where motor transport can never be expected to run.

2. That bridges should be designed on the basis of 10 foot lanes and that the general standard away from towns (in which wider bridges are frequently required) is a bridge with a clear width of 20 feet.

3. That the loading should be 12 B.E.S.A. units for span up to 100 feet decreasing to 8 units uniformly for spans from 100 to 300 feet.

4. That no impact need be added for main girders.

This report was considered by the Railway Bridge Standards Committee in March 1932 and they made the following recommendations to the Railway Board :—

"The opinion of the Committee is that a suitable impact allowance is necessary and this is also the opinion of Mr. K.G. Mitchell, Consulting Engineer to the Government of India. (Roads).

The Committee do not see their way to differentiate between classes of road bridges such as steel, timber, masonry and reinforced concrete. They have carefully considered the evidence available and particularly the Conference Specification for Highway Bridges compiled by a Conference Committee composed of representatives of the American Association of State Highway officials and the American Railway Engineering Association.

This specification gives the impact factor :—

$$I = \frac{50}{L+125}$$

where L=the length in feet of the portion of the span which is loaded to produce the maximum stress in the member considered. This formula gives a maximum of 40 per cent of zero span, 23 per cent in 100 feet and about 11 per cent on a 300 feet span.

The Committee agree to this allowance for spans of 100 feet and over, but consider it is too low for spans below 100 feet the reason being (which is shared by Mr. Mitchell) that the average conditions of road surfaces in India warrant a slightly higher value for short spans.

The requirements can suitably be met by adopting for all spans the impact formula

$$I = \tfrac{1}{2} \times \frac{65}{45+L}$$

previously recommended by the Committee, but subject to a maximum value of 50 per cent.

As a corollary to *our* recommendations we recommend the adoption generally of the classification for standard loadings given in Appendix V to the Proceedings of the Road Conference and its Committees (India), briefly as follows :—

Class A for special localities and industrial areas

„ B for general cases of all roads

„ C for light traffic

with the following specifications for each class :—

Class A :—The Standard adopted should be to suit local conditions.

Class B :—For spans or loaded *lengths up to 80 feet*—10 units of B.E.S.A. Road loading. For spans or loaded lengths exceeding 80 feet a reduction is proposed in the number of units of B. E. S. A. loading to be taken to provide for the lower average weight of vehicles on the longer spans. A sliding scale of units to be adopted from 10 at 80 feet to 6 at 300 feet is proposed, these loadings in all cases to be increased for impact as specified. This proposal for a sliding scale, it may be noted, is in conformity with the latest Ministry of Transport proposals and the American highway standards and is also forecasted in the Road Conference proceedings previously referred to.

Class C :—For spans or loaded lengths up to 80 feet—7 units of B.E.S.A. loading. For spans or loaded lengths exceeding 80 feet a sliding scale of units from 7 at 80 feet to 5 at 300 feet.

For all cases one line of traffic is assumed to occupy a 10 feet width of bridge It may be noted that provided a vehicle moves at a speed not exceeding 3 miles per hour, its impact effect can be neglected, the maximum permissible axle load can be increased by 50 per cent under our proposal.

Cases of special types of bridges such as a Suspension, Cantilever etc. should be considered on their individual merits."

The orders passed by the Railway Board on these recommendations are as follows :—

(a) " The Committee make 3 principal recommendations viz:—Highway impact allowances on bridges of timber, steel and stone should be indentical. This is accepted by the Board. Although the impact allowance on masonry arch bridges might be disregarded altogether, as recommended by the Indian Road Conference, the stresses due to the live load itself are relatively so small that it becomes immaterial whether impact allowances are added or not. It will be justifiable therefore to adhere to the same factor throughout.

(b) An impact for spans between 5 feet and 300 feet. The curve follows closely the American curve with an increase, in the case of spans of about 60 feet and under The curve falls between the Ministry of Transport 1931 curve and the American curve and gives a factor about 30 per cent less than did the curve in 13 (2) of the 1926 Rules.

No direct experimental data have been produced in support of this proposal but it is recognised that the collection of useful data is a matter of considerable difficulty on account of the fortuitous nature of the factors giving rise to road impact. The curve as now proposed is accepted subject to future modification which may be found necessary to differentiate between high speed vehicles on solid or pneumatic tyres.

(c) An equivalent loading curve for general and trunk roads for spans between 5 feet and 300 feet including the impact allowances proposed above.

The curve on short spans corresponds to 10 units B.E.S.A; loading with no additional knife edge load. This loading curve is about 30 per cent heavier than that proposed by the Indian Road Committee on spans below about 30 feet but approximates to it on spans above 30 feet and is nowhere appreciably below it. The proposed Class B loading is accepted subject to possible future modification in the permissible axle loading which may be found justifiable to differentiate between solid and pneumatic tyres."

In addition the Railway Bridge Rules were modified, chiefly as regards the design of main girders of combined rail and road bridges. As this type of bridge would always be constructed under the control of the Railway administration these provisions have not been taken into consideration here.

The views of Railway Engineers and the Railway Board are particularly worthy of consideration because the Railway Board maintains a body of Inspectors whose duty is to ensure the safety of all bridges. Any bridge falling below the standard set by the Rules passed and accepted by the Railway Board is scrapped. In passing their Rules therefore the Railway Board are influenced

by a due regard to economy and to the costly nature of adopting rules setting up an unnecessarily high standard.

The most prominent outcome of a study of the history of the proposals for standard loadings for road bridges is that the investigations hitherto have centred on selecting one or another fixed or variable number of British Engineering Standard Association units. The adequacy or otherwise of the B. E. S. A. unit loading in respect of Indian Road traffic has not, apparently, been taken in consideration.

It has been the object of the present investigation to repair this apparent omission, not so much with a view to setting up new standards but rather with a view of investigating actual prevailing conditions, the existence of any and the extent of limiting factors preventing increases of existing loadings, the strength and resistence of road surfaces and the average and maxima load intensities per lineal foot of loaded roadway that the common run of goods carried, width of vehicles, loading and unloading times and other similar practical considerations have developed in actual practice under the stress of commercial competition.

This investigation has comprised :—

1. A study of the various motor vehicle rules adopted by the various provinces under the Indian Motor Vehicles Act 1924.
2. An exhaustive analysis of existing motor vehicles of all kinds as actually made and used.
3. The observation of actual motor vehicle traffic and the main factors governing the management of its operation.
4. A study of the strength of road foundations.

PROVINCIAL MOTOR VEHICLES RULES.

Practically every province lays down that the heaviest vehicle shall not exceed 12 tons, that is heaviest axle shall not weigh more than 8 tons and that the heaviest axle weight of a trailer shall not exceed 4 tons.

In addition, the speed of such a vehicle, even if shod with pneumatic or solid rubber tyres, is limited to 7 miles per hour with a relaxation for maxima 6 tons axle weights of 12 miles per hour.

The number of trailers is limited to 3 or alternatively to a total length of coupled vehicles of 75 feet.

The exceptions are :—

Madras.	Nil.
Bengal.	Only one trailer.
Calcutta & Howrah.	Whilst conforming, envisages the use of a superimposed trailer and of six wheelers allowing a total laden weight of 16 tons to such vehicles with 12 tons on the two rear axles 8 ton axles are limited to 8 miles per hour.
Bihar & Orissa.	7.5 tons total laden weight, 5 ton axles: only two trailers with $2\frac{1}{2}$ ton axles Speed 8 miles per hour.
Punjab.	Trailers 5 tons, local authority vehicles can weigh 16 tons, heavy motor vehicles restricted to main roads,

United Provinces. As for Punjab.

Bombay. Permits a 14 tons traction engine with 3 trailers.

These rules have obviously not been drafted from the point of view of the design of bridges where the spacing of axles is all important, since frequently maxima axle spacings are imposed instead of minima. The objects in view seem to be the general safety of the public and roadside property and the prevention of the destruction of the roads themselves.

Since these rules can be altered by a stroke of the pen and since important variations exist already in different provinces they cannot form a firm basis for selecting a standard loading for bridges: they do, however, give a clear indication of the loads and speeds which are considered permissible and safe.

EXISTING VEHICLES.

The most important consideration to a bridge designer is not only what the maxima axle loads are likely to be but their spacing; in other words the length density of the load.

Here practical considerations are paramount. It is impossible to pile up loads on moving vehicles of a fixed width (7 feet 6 inches) indefinitely—in effect heights of vehicles are limited to 12 feet, often less. The loaded platforms of lorries and trailers have also definite limitations—both by rule and also by practical considerations. Another factor is that commercial lorries like cargo vessels and railway goods wagons must be made to take loads of average specific gravity.

It was thought that the best means of collecting reliable data was to study modern motor lorry practice as it seems reasonable to assume that the makers of these vehicles, exposed to competition, would concentrate their designing efforts on the production of vehicles which would be money earners for their owners.

Having come to this conclusion, it also became apparent that the information required was the average laden weight of commercial motor vehicles per foot of their overall length and the spacing of vehicles when moving and when standing still, coupled and in convoy.

After an exhaustive analysis of all lorries made in all countries of the world, remarkably uniform results were obtained. The results given below are not based on average, but are averages of the upper third of the figures obtained the best selling types being given weightage

Types of vehicles.	Laden weight per foot of length	Load capacity per 1 foot of loaded platforms.	Heaviest axle.
10 to 12 ton 4 wheelers	.52 T	.43 T	8 50 T
12 to 16 ton 6 wheelers	.58 T	.52 T	7 25 T
21 to 23 ton 8 wheelers	.78 T	.82 T	8.00 T

Observation of Traffic.

As regards the spacing of vehicles extensive observations have been made of actual road conditions, the drivers being Indians. The result is that for coupled vehicles the distance between vehicles is about 4 feet when moving the average distance between vehicles was found to be always more than 20 feet (see remarks under "SPEED") even in convoys of military lorries where the drivers are trained to keep close. When drawn up at stopping places, the distance apart was found to be five feet or more except in garages and parking places. This is, no doubt, owing to the height of the bonnet which makes the driver think he is closer to objects ahead of him than he actually is.

Speed observations were also made but the results are not very reliable owing to the extreme paucity of vehicles anywhere approaching the maxima weights given. There is no doubt that nearly 98 per cent of the motor vehicles at present in use do not exceed 6 ton total laden weight and even when overloaded (which they very frequently are) cannot weigh much more than 66 per cent of the loadings under consideration. Subject to this proviso, there is no doubt that the speed limits given in the provincial motor rules are persistently and universally ignored. Except on gradients, even the heaviest laden lorries with trailer travel at speeds between 15 and 23 miles per hour.

The comparative lightness of the motor vehicles now in general use should not have too great an influence on the decision. There is no doubt, from Makers lists, that 12 ton four-wheelers and 16 ton 6-wheelers are being made and sold in quantities in other countries and it would be a mistake to omit them from consideration. There is ample evidence indicating that at present lorry owners, in choosing the type of lorry to use, are influenced by factors liable to change. These are :—

1. Low wages of drivers,
2. Low standard of maintenance,
3. High cost of fuel and lubricants,
4. High import duties on vehicles, tyres and spares,
5. Short leads,
6. Quick turn rounds.
7. Limited capitals (small owners).

All these conditions militate against the general use of the heavier types but these types are available, are economical and are increasing in numbers in other countries. There is also a tendency towards the adoption of Diesel Engines which will lower costs; the gradual improvement of the surfacing of Indian roads will tend to stimulate long distance traffic requiring larger organisations commanding greater resources; the existing crushing import duties are likely to decrease. All these causes seem to make it necessary to accept the probability, that weights of vehicles will increase over the average weight of the vehicles now in general use.

There is also another important factor on which reliable evidence is available. It is the considered opinion of motor vehicles manufacturers that axles of more than 8 ton capacity can be ruled out. There is a host of practical reasons for this, such as cost of tyres, strength of wheels, bearings and springs as well as of chassis design that militate against it. It is also extremely difficult to design an economical 12 ton lorry on 4 wheels and the whole tendency is to go

for more axles and medium axle loads, because until the road systems of all countries have developed very considerably, heavy axles loads strictly limit the ubiquity of the vehicle and lead to trouble in bad weather and on inferior roads.

The only other combination that has to be considered in regard to maxima axle loads is the tractor or traction engine followed by a train of trailers. A general survey of the world position is that this type of road transport only survives in appreciable quantity in the United Kingdom and is decreasing even there, except for caravans, fairs and agricultural plant. For ordinary goods road traffic trains can only be used economically if there are large transport organisations carrying out long distance haulage contracts, otherwise the diversity and small size of consignments militate against voluntary acceptance of the main disabilities of railways and the surrender of the very qualities of rapid home delivery and collection which are enjoyed by and give advantage to road transport. The tendency now is to develop the caterpillar type of tractor for work off the roads, the road tractors being used only for very special loads carried generally on one trailer only of special construction. The idea of loading up the driven axle with the weight of propelling machinery instead of pay load is uneconomical and could only be generally accepted if extremely long trains of trailers become attractive. The weight of evidence is against this being a likely possibility.

Strength of Road Foundations.

This subject has an important bearing on the problem as even if the considerations outlined above be ignored and the assumption is made that the axle loads of road vehicles, like those of locomotives, will increase consistently over a large number of years, the strength of roads, either as they exist or as they can be made must obviously be an unavoidable limiting factor.

This conclusion leads to the consideration of the standard of Indian roads, as they are and as they are likely to be.

As the Chief Engineers stated in their report, outside cities or industrial areas, there can be only one standard of loading (no matter what the present conditions of any one road may be) and that standard of loading, as far as bridges are concerned, must logically be common to all roads where gradients, mountains and the like do not prevent the use of motor vehicles.

If this, the most logical, conclusion be accepted, it seems inevitable to conclude that the standard of road construction must also be the metalled road on rubble soling. It is inconceivable that strong reinforced concrete roads or their equivalent will be so common as to make it necessary to accept them as the standard of Indian road construction rather than as belonging to the special classification of the city or industrial area standard. This conclusion is strengthened by the fact that this is the case throughout the world if we except some very small areas of the United Kingdom and some special motor roads in the U.S.A. and Italy. Everywhere else the strong concrete road is a city or industrial area standard and likely to remain so for very many years to come.

The question therefore comes down to this—what is the greatest axle load which a metalled road with rubble soling can stand and keep the cost of maintenance within the limits of yearly maintenance budgets ?

Without experimental data of our own, the answer may well be sought in the maxima axle loads adopted by the manufacturers of heavy motor vehicles for the types most in demand. By these means we are really making a referendum of the motor transport owners and operators and of the Road Authorities

throughout the world. If it be accepted that this is the best source from which to seek our answer, there is no ambiguity in the reply.

The typical lorries Nos. 1 and 2 shown in plate No. 1 represent a four wheeler and a six wheeler which are typical of the heaviest type of vehicle which sells readily all over the world. There are very few types which impose more severe loadings, some owing to one particular, some owing to others, but even if such vehicles should come into moderately general use, it is not unreasonable to assume that strings of these types would not cover both tracks of a bridge. There is also the safeguard that if vehicles are passed over a bridge at 3 or 4 miles per hour an overload of 50 per cent is permissible.

Comparison with B. E. S. A. Unit Loading.

A glance at plate No. 1 reveals the essential differences between these practically evolved standard types and the B E.S A. unit loading. The latter only allows 10 feet between the leading axle of one train and the last axle of a preceding train, a condition quite unattainable in practice when the trains are in motion at speeds producing impact. The wheel base of the tractor and the spacing between the driving axle and the first axle of the trailer are also smaller than what obtains in actual practice. Against this, the B.E.S A. unit loading trailers are proportionally lighter than the trailers in general use.

The effect of these differences is that the use of the B.E.S.A. unit loading penalizes all the most commonly used spans, say up to 100 feet, and is too light on the longer spans, if the 4 ton axle load for trailers and the three trailer plus lorry train contemplated in the provincial motor vehicle rules be accepted.

The Proposed Standard.

Maximum bending moments at the centre of span have been calculated and equivalent uniformly distributed loads for the maximum of the following loadings have been plotted on plate No. 2.

1.	For a series of standard type 4 wheelers.					
2.	,,	,,	,,	,,	,,	followed by one trailer.
3.	,,	,,	,,	,,	,,	followed by two trailers.
4.	,,	,,	,,	,,	6 wheelers.	
5.	,,	,,	,,	,,	,,	followed by one trailer.
6.	,,	,,	,,	,,	,,	followed by two trailers.

It was found that case No. 6 gives the ruling or greatest bending moments except for very short spans where the 8 ton axle of the 4 wheeler has a greater effect. The curve for the standard 6 wheeler with 3 trailers has not been shown because this gives a length of train exceeding 75 feet which is barred by the Rules.

From these curves an eveloping curve was deducted and is shown as the red "Indian Standard" curve.

It can be defined as a constant uniform load of 0.34 tons per 1 foot of each traffic lane plus a knife edge load of 6 tons for computing bending moments, or of 9 tons for computing shears with the limitation that for computing bending moments the total distributed load on spans of 20 feet and under shall never be less than 6.8 tons per lane of traffic over the whole span.

This description dispenses with the use of tables, can be readily memorised and is simple and handy for the computor.

In plate No. 3 the central Bending Moments due to this standard plus the impact increment recommended hereafter, has been plotted together with the bridge loadings adopted by the various provinces of India plus the impact increments that have been laid down.

The Indian Heavy Standard.

Having discovered an easy way of computing bending moment curves it was thought desirable to extend the consideration of practical loadings to the maxima loadings probable in industrial areas and big towns, which the Chief Engineers and the Railway Board left undefined.

The investigations into the types of motor vehicles actually made and sold in quantities indicated that the choice was not so indeterminate as would appear at first glance. Reference has already been made to the well established tendency to increase the capacity of motor vehicles not by increasing the axle loads (as is envisaged in the B.E.S.A. loadings) but rather by increasing the number of axles and the length of the vehicles. The practical reasons for this tendency have been given above and need not be repeated here but their cogency is indisputable.

It has therefore appeared feasible to produce a type loading for the heaviest motor vehicles which can be or are likely to be produced. It cannot be said that vehicles of higher carrying capacities cannot be produced or will not be produced. They undoubtedly can. But the point is that, in accordance with all the evidence, such increases can only be obtained by increasing the numbers of axles not by increasing the axle roads. So long as development of carrying capacity follows these lines, the capacity of bridges will not be materially affected as it is of indifference to the bridge designer whether a series of axle loads are those of a lorry or those of a trailer. The important thing is that the maximum longitudinal density of loading which can practically be obtained with 8 ton axle loads be ascertained.

It is on these principles that the heavy loading type vehicle shown on the plate has been constructed representing an 8 wheeler with 8 ton axle loads followed by trailers with 6½ ton axle loads.

There is ample evidence that a bridge designed to carry a series of such loads will carry any type of road motor vehicle which it is commercially possible to build.

This loading can be defined as a constant uniform load of 0.58 tons per lineal foot of each traffic lane plus a knife edge load of 7 tons for computing Bending Moments, or of 10 tons for computing shears, with the limitation that for computing bending moments the total distributed load on spans of 20 feet and under shall never be less than 11.6 tons per lane of traffic over the whole span.

Exceptions

In defining the loadings of the new Howrah Bridge the Mookerjee Report envisaged a 50 ton boiler truck. In considering the design the Consulting Engineers found it unnecessary to depart from this suggestion as, on the wide carriageway in question, the ordinary loadings on the 6 traffic lanes provided produced a greater effect than a 50 ton boiler truck if passed over the bridge on the traffic lanes nearest to the main trusses and when there is no other traffic.

In considering standard loadings for Indian road bridges it has not seemed advisable to penalize the whole road development of the country by attempting

to cater for such special and exceptional loads. It has been thought preferable to select a reasonable heavy standard and extend its application to all areas within municipal limits, notified areas, industrial areas and particular main roads where the nature of the traffic is such that strong reinforced concrete foundations have been provided or are likely to be provided.

This appears logical. In addition to the heavier burdens and special freight loads likely in industrial areas, municipal vehicles, sanitary, fire fighting and street watering, show a tendency to be more ponderous than ordinary long distance traffic vehicles. It is also undeniable that road traffic composed of the type vehicles of the Indian heavy standard, if at all dense, would destroy the best metalled road on rubble soling in a very short time and that a solid concrete foundation is an essential concomitant to their circulation.

Impact Factor.

This question has been given very careful consideration by the Railway Board and all their very qualified advisors who have, for some years, now been conducting careful impact experiments on railway bridges. The result of their labours can be studied in the annual reports of the Bridge Standards Committee and reveal a record of extremely interesting research and provide a mass of valuable information. It is true that railway impact effects are not on all fours with road vehicle impact effects but they have a good deal in common.

The railway impact effect has been analysed to consist of:—

1. Hammer blows, consisting of the effects due to:—
   (a) over balance of revolving parts,
   (b) the acceleration and deceleration of the reciprocating par acting through an inclined connecting rod,
   (c) the steam force on the piston.
2. Lurching.
3. Track irregularities.
4. Speed of application of live load.

All the effects in Item 1 have been calculated and verified practically. Extensive tests on spring deflections of locomotives have been carried out to measure the lurch and by subtracting these factors from the total impact effects an approximation to the effect of rail joints has been obtained.

These results are far in advance of anything done in other countries and it would seem reasonable to accept the views of the men who have themselves carried out these investigations even though not based on actual road bridge tests, until the road Engineers of India carry out a similar research of their own on road bridge impact effects. Should such a course be decided on the experience of the Railway Bridge Engineers especially as regards recording apparatus and methods of carrying out test will be found especially valuable and will save considerable preliminary work and expense.

Another factor is that the demand for the replacement of level crossings by overbridge is likely to increase and it would be illogical to have two sets of standards, one for road bridges over Railways and another for road bridges over rivers.

Failing a research into impact effects on road bridges by the Road Engineers in India on the results of which a rational impact formula could be

formulated, acceptable to all, the only choice which will secure uniformity is the formula chosen by the Railway engineers for their own road bridges.

This formula has the advantage that the impact increase, whilst considerable on bridge members which are stressed most when the loaded length is 20 feet and under (floor systems), is at the same time quite moderate on loaded lengths of 80 feet and over (main girders). In the case of concrete bridges of 100 feet span or more the main girders or arches will weigh several times the live load, so that a moderate increase in the latter would only mean an insignificant increase on the total loaded weight of the bridge.

In such circumstances, as the Railway Board correctly state, their formula can be of universal application to road bridges of any material, because where the formula has a large effect, viz. on the floor systems, all bridges, whether of concrete or steel, usually use some from of concrete slab or the like and are thus logically and correctly on a par. Where, as in arch spans of fair size, the concrete bridge is more massive than the steel bridge the formula provides such slight increases in the live load that, in the case of the concrete bridge, the increment is so small as to render it unnecessary to differentiate between concrete and other materials.

The Railway formula for impact on road bridges has therefore been proposed in the draft specification but has been slightly modified in order to take into account the relaxation (permissible for wide bridges) representing the improbability of each traffic lane of a road bridge being loaded up to the full standard loading and impact (which is a maximum) simultaneously.

The Railway Board formula is:—

$$\tfrac{1}{2}\times\frac{65}{45+L} \text{ subject to a maximum of 50 per cent.}$$

The proposed formula is:—

$$\tfrac{1}{2}\times\frac{65}{45+\frac{(n+1)}{2}L} \text{ subject to a maximum of 50 per cent.}$$

where L is the loaded length which gives the maximum stress in the member under consideration and n is the number of 10 feet traffic lanes.

In plate No. 4 the proposed standard loadings (plus impact for one lane of traffic) have been plotted together with the Railway Board "B" class loading for comparison.

Classification of Roads.

Having selected the two standard loadings viz. the "Indian Standard Loading" and the "Indian Heavy Standard Loading" and the Impact increment, it only remains to define the class of roads to which each loading is to apply.

The definition that covers all the premises of the foregoing discussion would appear to be:—

Indian Heavy Standard:—To be used for designing road bridges for all roads within municipal limits, notified areas and industrial areas and for all other roads which are already provided with a strong reinforced concrete or equivalent foundation or are likely to be so provided.

Indian Standard Loading :—To be used for designing road bridges for all roads in India which carry or may carry motor traffic which are not comprised in the Heavy Standard Classification above.

A third standard loading to apply to roads where only 30 cwt. lorries and buses are allowed to run has also been investigated but the resulting loadings come so far below the loading due to a crowd of 84 pounds per square foot that the idea was dropped.

The effect of a crowd is less than the Indian Standard Loading advocated above, but the difference is not large enough to justify a third light standard based on the crowd load and *light* vehicles with effects equal to or less than the crowd load.

In addition the classification adopted by the Chief Engineers is so simple and logical that only the very strongest reasons could justify any proposal to modify it.

Letter from Mr. W. J. Turnbull of THE CONCRETE ASSOCIATION OF INDIA, BOMBAY. No. R/47/11031 dated the 7th July, 1936 to Mr. W. A. Radice, Calcutta.

I have now gone through the papers enclosed with your A/729 of the 12th June, (not reproduced).

Proposed Standard Loading—I agree with your proposals.

Impact Factor—It would appear to be the opinion of many bridge authorities that a lower impact factor should be applied to certain types of reinforced concrete highway bridges, and in this connection I am enclosing a few authoritative references (reproduced below) which I have collected.

I do not wish to stress this point unduly at present as in common with yourself I think it is of vital importance that standard specifications should be evolved with as little delay as possible.

I suggest therefore that your note should be put forward as it stands together with the enclosed references, and that the main committee should decide whether steel bridges and reinforced-concrete should be treated alike as regards the impact factor.

Weight of Reinforced Concrete—The generally accepted weight per cubic foot is 150 pounds and not 160 pounds as mentioned on page 5 of your specifications.

I think you can send the combined final draft direct to Mr. K. G. Mitchell without any further reference to me.

I. IMPACT.

The percentage increase of loading to cover impact stresses specified by the Ministry of Transport in the case of large span bridges is somewhat high. This increase of 50 per cent. is that usually applied to reinforced concrete railway bridges, and in other countries one half this amount (25 per cent.) is generally adopted as the impact allowance for ordinary rolling loads on reinforced concrete structures. This amount is further greatly reduced, or even excluded entirely, for all members other than those comprising the actual deck construction.

The question of impact introduces a time factor which in turn inevitably involves the mass or inertia of the structure subjected to it. For this reason, and owing to the molecular structure of concrete itself, vibratory stresses are less in a concrete bridge than in a steel structure of the same strength. The speed of the vehicle causing impact is also obviously of the greatest importance, and, while lighter and faster vehicles may cause higher impact stresses, the standard loading in question must always be of comparatively low speed and the percentage increase therefore relatively small.

Furthermore, the proximity of a member under investigation to the point of load application is important as regards the effect of impact upon the stresses produced in the member. The method adopted by the Ministry of Transport of increasing the static load by 50 per cent. results in this increased load being applied to all members comprising a bridge of any type, and consequently some of the members remote from the load are designed to resist impact stresses which cannot conceivably affect them. The Continental method of specifying a decreased permissible working stress varying in amount according to the proximity of the members to the load is considered by many responsible engineers to be the most efficient and proper method of dealing with impact stresses.

It should be noted that in some small bridges an impact allowance of 50 per cent. may be, if anything, on the low side, especially for bridges of the girder type. Reinforced concrete slabs, if properly designed, possess remarkable resistance to loading of all kinds, and it is for the beam members of such bridges that care should be taken with regard to impact stresses.

(Extract from Reinforced Concrete Bridges—by W. L. Scott—Page 9.)

II. A Comparison between Reinforced Concrete and Steel from the Point of View of Bridge Dynamics.

The dead weight of a reinforced concrete bridge is usually considerably higher than that of a steel structure of equal carrying capacity; consequently the live load produces a much smaller increase of stress in the reinforced concrete structure. The Author discusses the dynamical effect of the passage of the live load across a bridge, under the following heads :—

(1) The Zimmerman effect, produced by the centrifugal force developed by the live load an account of the curvature of its trajectory when passing over the deflected line of the bridge ; this can be avoided by giving the structure a proper camber. The Author states that the increase of stress due to this effect in a reinforced concrete bridge would be about three-quarters of that for a steel bridge. (2) The Timoshenko effect, or the magnification of the load produced by the shockless oscillations of the bridge generated by the passage of the load: this depends upon the frequency of vibration of the structure, the frequency of reinforced concrete being about 63 per cent. Higher than that of steel. According to to the Author's calculation, the increase of stress in a reinforced concreat bridge due to the Timoshenko effect would be about 15 per cent. less than in a steel structure. (3) Direct shock produced by the Impact of a load falling on to the structure, *e g.* a wheel at an open rail-joint. In this case the stresses in reinforced concrete are greater than in steel when the span is less than 32.8 feet; for longer spans the reinforced concrete stresses are the smaller.

(4) Hammer-blow caused by the effect of unbalanced rotating masses on a vehicle. The Author states that the stresses in a reinforced concrete bridge due to hammer-blow are 89 per cent of those in the corresponding steel bridge. He concludes that for medium-span and long-span bridges a lower impact allowance should be made when reinforced concrete is used, but that for spans of less than 32.8 feet exposed to shock loading, a larger impact allowance is required. R. Tillmann. (Ost. Ing. Arch. Ver. 81,420-424).

(Extract from Engineering Abstracts, New Series No. 43. April, 1930).

III. The Adolphe Bridge over the Pertrusse Valley, Luxemburg.

The Author describes tests made with deflectometers, extensometers, seismographs, and other apparatus on the Adolphe bridge—a masonry arch of 82.2 metres (269.7 feet) span and 21.83 metres (71.6 feet) rise—with the object of ascertaining the behaviour of such a structure under test-loads consisting of heavy vehicles, and also under the action of an oscillator giving a pulsating force at various frequencies of revolution. The results indicate that the material behaves elastically with little permanent set. The vertical deflexion at the crown under a test-load of 225¼ metric tons distributed over a length of 41.42 metres (135.9) feet was 1/53,000 of the span, and was very small under a distributed load of 650 kilograms per square metre (133 pounds per square feet). The greatest compressive stress at the crown, assuming a modulus of elasticity of 2,540 tons per square inch was 122 pounds per square inch, and with one exception the tensile stresses measured were less than the calculated values. The impact-coefficient during the passage of lorries at a speed of 15 kilometres (9.3 miles) per hour was 30 per cent; for tramwaycars and lorries at 12.15 kilometres (7.5—9.3 miles) per hour it was 10 per cent. The natural frequency of the arch was found to be 4 periods per sec., the amplitude of vibration being ±0.474 millimetres (0.0186 inch). At the quarter-span the direction of oscillation during resonance was oblique and nearly perpendicular to the axis of arch. Under a test-train the maximum vibration at the crown was ±0.14 millimetres (0.0055 inch), but the longitudinal vibrations were extremely small except when the test-vehicles were braked suddenly.

Mo Ros. (*Ann. P. et 6.105-ii 469-506).

(Extract from Engineering Abstracts, New Series No. 67, April, 1936).

BRIDGE ENGINEERING.

BY

WADDELL VOL. 1

Extract from page 131.

"The author is now employing the impact values given by the curves of Fig. 70 for electric railway loads on Highway bridges. Furthermore, for both highway and electric-railway loadings, the full values are used for timber floors only. *For concrete slabs on steel bridges, they are reduced one-fourth; and for reinforced concrete structures one-half*".

SUPPLEMENTARY NOTE ON STANDARD LOADINGS AND IMPACT

BY

Mr. W. A. Radice.

Impact :—In his letter No. R./47/11031 dated the 7th July 1936 Mr. W. J. Turnbull states that in the opinion of many bridge authorities a lower impact factor should be applied to certain types of reinforced concrete bridges and in support he encloses a few authoritative references collected by him for the perusal of the Main Committee.

In my original Note (see pages 377–401) I explained how I came to select the formula $\frac{1}{2} \times \frac{65}{45 + L\frac{(n+1)}{2}}$. In doing so I followed the decision of the Director of Civil Engineering to the Railway Board regarding proposals by the Railway Standards Committee. Briefly summarised these were :—

1. That with the present imperfect knowledge of impact effects this formula seemed reasonable.
2. That it is convenient to have the same formula for all types of bridges.
3. That the effect of this desirable uniformity whilst erring perhaps on the side of severity in the case of certain types of concrete bridges, was so small in comparison to the dead weight of the structure that the desirability of uniformity preponderated.

Like most other questions of this kind a decision must be based on quantitative factors rather than on general statements and I have therefore collected quantitative data.

Referring to Mr. Turnbull's references, we have the following :—

1. Impact factor specified by Ministry of Transport is 50 per cent for all spans and is usually applied to reinforced concrete bridges.

   In other countries the impact factor for reinforced concrete structures is 25 per cent and this is reduced or even excluded entirely for parts not in the deck.

2. The Zimmerman effect referred to due to centrifugal force is extraneous to this discussion and is dealt with in a separate clause.

   The Timoshenko effect due to speed of load is about 15 per cent less for a concrete bridge than a steel bridge. Shock effects are greater for concrete bridges up to a 33 feet span, smaller in longer span. Hammer blow effects in a concrete bridge are 89 per cent of those in a steel bridge.

3. In the Adolphe bridge, Luxemburgh, actual deflectometer, extensometer and seismograph experiments showed that in a masonry arch of 270 feet lorries produced 30 per cent impact and tramcars 10 per cent.

4. Waddell uses 50 per cent only of his impact factors in the case of concrete bridges.

In comparison with the above authoritative references I reproduce the actual impact factors recommended by the Railwayy Board and adopted by me in the proposed standard specification.

Impact factors :—

BRIDGE WIDTHS

Span.	*1 Track.*	*2 Track.*	*3 Track.*	*4 Track*
60 ft.	0.2825	0.2047	0.1970	0.1666
80 ft.	0.2600	0.1970	0.1585	0.1328
100 ft.	0.2242	0.1667	0.1327	0.1102
120 ft.	0.1968	0.1446	0.1141	0.0940

The corresponding impact factors recommended by Waddell as reduced for concrete bridges are :—

Span.	*1 Track.*	*2 Track.*	*3 Track.*	*4 Track.*
60 ft.	0.1925	0.1050	0.1300	0.1150
80 ft.	0.1775	0.1375	0.1125	0.0950
100 ft.	0.1700	0.1250	0.1000	0.0850
120 ft.	0.1575	0.1150	0.0900	0.0725

Below are given examples of 5 actual concrete bridges and the effect of the above small differences on them.

1. **Celular Spandrel Arch** :—72 feet span, 24.5 feet roadway (3 lanes of traffic).

Dead load	417 tons
Live load	146 ,,
Total load	563 tons

Impact allowance by proposed formula 25 tons being 4.45 per cent of total load.

,, ,, Waddells factor 17.8 tons

Difference 7.2 tons being 1.28 per cent of total load.

2. **Open Spandrel Arch** :—235 feet span, 23 feet roadway (2 lanes of traffic).

Dead load	2,683 tons
Live load	286 ,,
Total load	2,969 tons

Impact allowance by proposed formula 24 tons being 0.79 per cent. of total load.

,, ,, Waddells factor 21.5 tons

Difference 2.5 tons being 0.084 per cent of total load.

3. **Open Spandrel Arch** :—22 feet span, 33 feet roadway (3 lanes of traffic).

Dead load	2,529 tons
Live load	407 „
Total load	2,936 tons

Impact allowance by proposed formula 27 tons being 0.79 per cent of total load.

„ „ „ Waddells factor 24.4 per cent.

Difference 2.6 tons being 0.089 per cent of total load.

4. **Open Spandrel Arch** :—158 feet span 49 feet roadway (5 lanes of traffic).

Dead load	3,211 tons
Live load	493 „
Total load	3,704 tons

Impact allowance by proposed formula 31 tons being 0.84 per cent of total load.

„ „ Waddel formula 22.1 tons

8.9 tons being 0.024 per cent of total load.

5. **Bowstring Girder (Concrete)** :— 135 feet span, 17 feet roadway (2 lanes of traffic).

Dead load	3,369 tons
Live load	1,193 „
Total load	4,562 tons

Impact allowance by proposed formula 157 tons being 3.44 per cent of total load.

„ „ „ Waddell factor 119 tons

Difference 38 tons being 0.83 per cent of total load.

The differences in using the factors proposed by Mr. Turnbull's 4th authority and the proposed formula are respectively :—

1.28 per cent, 0.084 per cent, 0.089 per cent, 0.024 per cent and 0.83 per cent of the total load.

It would appear that the Railway Board's technical advisers were quite justified in stating that differences would be so small as to be insignificant when weighed against the advantages of uniformity.

The above tables also show that the proposed impact allowances are well below those mentioned in Mr. Turnbull's 1st authority.

The proposed formula gives an impact factor of 10.3 per cent for the Adolphe bridge quoted by Authority No. 3 against a measured effect of 30 per cent from lorries and 10 per cent for tramways.

Steam Rollers:—Practically every province has adopted the 15 ton steam roller plus a crowd preceding and following it plus 25 per cent impact.

It is well established that a vehicle moving at 3 to 4 miles an hour produces practically no impact effect.

The only possiblo way in which a steam roller could produce a very slight impact effect is if one of its wheels goes over a large stone which does not crush under it.

The heaviest wheel is less than 6 tons so that even if this be doubled the total weight put on the bridge cannot exceed 15+6=21 tons.

The loadings recommended by me for a 2 traffic lane bridge are:—

	Live Load.	Impact Allowance.	Total.
60 ft. span	52.8 tons	12.7 tons	65.5 tons
90 " "	66.4 "	13.1 "	79.5 "
100 " "	80.0 "	13.3 "	93.3 "
120 " "	93.6 "	13.5 "	107.1 "

It must be apparent that the effect described above is insignificant by comparison, even if we leave out of account the impossibility of having a roller in motion with the bridge fully loaded with fast moving lorries.

OPINIONS OF CHIEF ENGINEERS ETC.

Madras.

Plate No. 3 appended to my original note on Standard loadings and impact herewith shows that the proposed standard loading plus impact is practically indentical with the Madras standard loadings plus impact as specified.

There seems to be no reason why the proposed loadings and impact should not be adopted as all the Madras standard designs would not be affected. In new designs the proposed loadings produce much simpler calculations for floor systems. In a recent case I had this worked out. Using the Madras specification 14 sheets of calculations were necessary. With the proposed standard 2 sheets sufficed. The result was indentical.

Central Provinces.

A standard loading derived as in my original note seems more in accord with realities than a varying number of B.E.S.A. units for the reasons given therein.

Burma—6.

There is a wealth of data proving that impact effects increase the stresses in the main girders of a road bridge. The logical way to allow for a variable impact effect is to use a variable impact factor and not by varying the standard static load.

Bihar and Orissa.

The loadings used in this province are definitely lower than in any other province. Whether it is wise to limit the capacity of motor traffic for a considerable number of years is doubtful and it seems false economy not to cater for probable future development. The history of Indian railway bridges clearly

shows the vast sums of money required to raise the loading standards on existing bridges.

I doubt whether the small difference in cost of girders that would be caused by the higher standard proposal would in reality hinder development as such extra cost in new construction represents less than 1/1000th of the cost of a new road.

The suggestion that impact measurements should be carried out is an excellent one but it should be realised that a satisfactory investigation would be both costly in apparatus and personnel but would take a considerable time.

United Provinces.

As no grounds are given for the recommendations made it is difficult to express an opinion.

Bombay.

The Bombay standard for bridges up to 30 feet span is clearly much heavier than the makers of mechanical transport envisage. Otherwise the proposed loadings seem to conform closely with their requirements (see plate No. 4).

Army Headquarters.

The same remarks as apply to Bihar and Orissa apply to Baluchistan and transborder areas. It would seem a mistake to limit permanent bridges to the bare military requirements as the civil mechanical transport has developed recently to an enormous extent. So far private owners have chiefly relied on military surplus sales for their transport but when this source of supply is exhausted modern heavy vehicles will begin to circulate in those regions.

APPENDIX III.

INDIAN ROADS CONGRESS

List of Papers in Annual Proceedings

Volume I—1934.

Volume II—1936.

14. Analysis of Delhi Road Traffic Census by R. L. Sondhi, I.S.E.

15. A study of the relationship between vehicular traffic and road surfaces as affecting the selection of an economic road surface by H. P. Sinha, I.S.E., and A. M. Abbasi.

16. Traffic census and road diagrams by Lt.-Colonel W. deH. Haig, D.S.O.

17. Economics of road maintenance by S. Bashiram, I.S.E.

18. Necessity for surface treatment of important tourist lines and some aspects of economical work in that direction by V. S. Srinivasaragha Achariar Avl.

19. Treatment with molasses of the Bangalore-Mysore Road by Diwan Bahadur N. N. Ayyangar, B.A., L.C.E., M.I.E. (Ind)., I.S.E.

20. The Road problem in India with some suggestions by Colonel G. E. Sopwith.

21. General review of the results of recent road experiments in India as revealed by modern practice by K. G. Mitchell, C.I.E., I.S.E.

22. Road Research and Results by C. D. N. Meares.

23-(*a*). Roads in rural areas (Village Roads) by Hony. Captain Rao Bahadur Choudhry Lal Chand, O.B.E., M.L.A.

23-(*b*). Gravel roads by Diwan Bahadur N. N. Ayyangar, B.A., L.C.E., M.I.E. (Ind), I.S.E.

23-(*c*). Vitrified bricks for surfacing roads in deltaic districts by G. Gopala Acharya.

24. Oil as a binder for earth and gravel roads by T. G. F. Hemsworth, B.A., B.A.I., I.S.E.

25. Cement bound roads by W. J. Turnbull, B.Sc., M. Inst. C.E.

26. The necessity for a reasonably uniform standard loading for design of concrete bridges and a suitable loading for such and other types of bridges on highways in India by M. G. Banerji, B.A., B.E., A.M. Inst. M. & Cy. E., M.A.E., F.S.Sc.

27. Design of highway bridges. The necessity for an All-India specification by W. A. Radice, B.A., A.M.I.C.E., G. Wilson, B.Sc., A.M.I.C.E., and P. F. S. Warren, B.A., A.M.I.C.E.

28. Permissible stresses in concrete bridge design by W. J. Turnbull, B.Sc., M. Inst., C.E.

29. Regulation and control of motor transport in Mysore by H. Rangachar, M.A.

30. The construction of the Shillong-Jaintiapur Road in the Khasi Hills, Assam, by F. E. Cormack, I.S.E.

31. A method of rapid road reconnaissance by Captain W. G. Lang Anderson, R.E.

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APPENDIX IV.

LIST OF MEMBERS OF THE INDIAN ROADS CONGRESS, JUNE 1937.

Mr. K. G. Mitchell C.I.E., Consulting Engineer to the Government of India (Roads), New Delhi/Simla.

Mr. R. L. Sondhi, Executive Engineer, Provincial Division, Simla.

Mr. Guthlac Wilson, Engineer, Braithwaite Burn and Jessop Construction Company, Calcutta.

Mr. P. F. S. Warren, Director, Jessop & Co. Ltd., Calcutta.

Mr. W. A. Radice, Technical Adviser, Braithwaite Burn & Jessop Construction Co., Calcutta.

Mr. Alexander Jardine, Director, Jessop & Co. Ltd., Calcutta.

Mr. H. W. T. Hain, Managing Director, Braithwaite & Co. (India) Ltd., Calcutta.

Mr. Rathlin J. C. Tweed, Work Manager, Braithwaite & Co. (India) Ltd., Calcutta.

Mr. B. N. Mookerjee, c/o Martin & Co., Calcutta.

Mr. Kenneth Chatterton, Manager, Structural & Bridge Building Department, Burn & Co. Ltd., Howrah.

Mr. E. O. Pearce Departmental Manager, Engineering, Bird & Co., Calcutta.

Mr. S. A. Roberts, Partner, Bird & Co., Calcutta.

Mr. N. V. Modak, City Engineer, Bombay Municipality, Bombay.

Rai Sahib Hari Chand, Concrete Association of India, Lahore.

Mr. G. W. D. Breadon, District Engineer, Gurdaspur.

Mr. D. G. Sowani, Executive Engineer, Kolhapur State, Kolhapur.

Mr. M. C. Gupta, Municipal Engineer, Allahabad.

Mr. D. W. Goghari, Retired State Engineer, Bhavnagar.

Mr. G. P. Bhandarkar, Chief Engineer, Holkar State, Indore.

Mr. A. K. Datta, Private Consulting Engineer, Calcutta.

Mr. T. Campbell Gray, Shalimar Tar Products Ltd., Madras.

Mr. S. N. Chakravarti, I.S.E., Municipal Engineer, Delhi.

Mr. T. R. Sneyd-Kynnersley, Co-Manager, Concrete Association of India, Home Street, Bombay.

Mr. W. J. Turnbull c/o Shalimar Tar Products (1935) Limited, Bombay.

Mr. G. B. E. Truscott, Chief Engineer, Public Works Department, Travancore.

Lt.-Col. H. C. Smith, M.C., O.B.E., General Secretary, Indian Road and Transport Development Association, Bombay.

Mr. D. Nilsson, Chief Engineer, and Director, J. C. Gammon and Co., Bombay.

Mr. D. E. Gough, Representative of the Society of Motor Manufacturers and Traders Ltd., Bombay.

Mr. E. A. Nadirshah, Deputy Chief Engineer, Bombay Municipality.

Dr. M. A. Korni, Chief Engineer, Reinforced Concrete Department of Bird & Co., Ltd., Calcutta.

Mr. H. M. Surati, Divisional Engineer, Roads, Hyderabad (Deccan).

Mr. A. Lakshminarayana Rao, District Board Engineer, Masulipatam, Kistna District.

Mr. Pestonji L. Golwala, Civil Engineer, Bombay.

Sirdar Shiv Prasad, Assistant Engineer, Patiala State, Patiala.

Khan Bahadur J. R. Colabawala, State Engineer, Khairpur Mirs (Sind).

Mr. J. S. Narasimham, Hyderabad (Deccan).

Col. G. E. Sopwith, General Manager, Shalimar Tar Products Ltd., Calcutta.

Mr. J. R. Jussawala, State Engineer, Cambay.

Mr. V. H. Sadarangani, College of Engineering, Madras, Saidapet.

Mr. Syed Arifuddin, Superintending Engineer, Public Works Department, 4th Circle, Hyderabad (Deccan).

Mr. Jagmohandas T. Mehta, Town Roads Supervisor, Vadva (Bhavnagar State).

Mr. S. V. Jagjivan, Sub-divisional Officer, Khairpur Sub-Division, Khairpur Mirs (Sind).

Mr. B. R. Malhotra, Offg. Executive Engineer, Bilot Division N.W.F. Province.

Mr. S. M. Gupta, Assistant Engineer, Public Works Department, Pegu, Burma.

Mr. Anant Balavant Haval, Ilakka Panchayat Engineer, Shukrawar Peth, Kolhapur.

Mr. B. Narasimha Shenoy, District Board Engineer, Chittoor.

Mr. R. J. Kelly, Assistant Executive Engineer, Dehra Dun Central Division, Dehra Dun.

Mr. B. St. J. Newton, Offg. Superintending Engineer, Raipur Central Provinces.

Mr. Hardit Singh, Assistant Engineer, Public Works Department, Mardan, N. W. F. Province.

Lt.-Col. H. S. Northey, Superintending Engineer, Madras P. W. D.

Mr. Brij Mohan Lal, Executive Engineer, P. W. D., Lahore.

Rao Saheb V. G. Bhave, State Engineer, Sangli.

Mr. M. R. Patel, Executive Engineer, Navsari (Baroda State).

Mr. Madho Prasad Srivastava, District Board Engineer, Lucknow.

Mr. A. C. Mukerjee, Executive Engineer, Provincial Division, Lucknow.

Mr. G. Gopala Acharya, Assistant Engineer, Public Works Department, Lalgudy (Trichy District).

Khan Bahadur M. Z. A. Faruqui, Executive Engineer, Central Public Works Department, New Delhi.

Mr. H. Ramaswamy, District Board Engineer, Dharwar, (Bombay Presidency).

Mr. K. L. H. Wadley, Superintendent, Viceregal Estate, Simla.

Mr Manohar Nath, Executive Officer, Municipal Board, Meerut.

Mr. Majidullah Khan, Executive Engineer, Public Works Department, Bannu.

Mr. S. Bashiram, Superintending Engineer, II Circle, Ambala.

Mr. V. S. Srinivasa Raghava Acharyar, District Board Engineer, Cuddalore N. T. (South India).

Mr. Jagdish Prasad, Assistant to the Consulting Engineer to the Govt. of India (Roads).

Mr. Bishamber Dyal, District Engineer, Rohtak.

Mr. C. R. Katkoria, State Engineer, Cutch State, Bhuj.

Mr. G. M. Mckelvie, Executive Engineer, Public Works Department, Akola (Berar).

Mr. G. Fairs, Sub-Divisional Officer, Public Works Department, Dera Ismail Khan.

Mr. Ishtiaq Ali, Assistant Municipal Engineer, Delhi.

Mr. A. Vipan, Chief Engineer, Government of Orissa, Public Works Department, Cuttock.

Mr. S. K. Ghose, Assistant Engineer, P.W.D., P.O. Sitamarhi, Dumra.

Mr. T. R. Ramaswami Iyer, Ramnad District Board Engineer, Madura.

Mr. C. P. M. Harrison, Chief Engineer, Bengal, Department of Communications and Works, Calcutta.

Rai Bahadur S. N. Bhaduri, Chief Engineer, Gwalior Public Works Department, Gwalior.

Mr. V. P. Bedekar, State Engineer, Miraj (Senior) (Deccan State).

Mr. R. H. T. Mackenzie, Chief Engineer, Bikaner State, Bikaner.

Rai Bahadur A. P. Varma, Chief Engineer, Patiala State, Patiala.

Mr. B. D. Nanda, Divisional Engineer, Gilgit Division, Bandipur (Kashmir).

Mr. J. C. Sahney, Assistant Engineer, Public Works Department, Fyzabad (U.P.)

Mr. Jagmohanlal Bhatnagar, State Engineer, Jhalawar State, Brijnagar (Rajputana).

Mr. M. J. Shah, Road Engineer, Rajkot State, Rajkot Civil Station (Kathiawar).

Mr. Y. K. Ghanekar, Assistant Engineer, Kolhapur State, Kolhapur.

Mr. Lekh Raj, Civil Engineer, Kapurthala State, Kapurthala.

Mr Khairuddin Ahmed, Executive Engineer, Public Works Department, Waheed Munzil, St. Georges Church Lane, Hyderabad (Deccan).

Mr. G. Reidshaw, Chief Engineer and Secretary to the Govt. of Assam, Public Works Department, Shillong.

Mr. K. Rangaswami, State Engineer, Pudukkothai State, Pudukkothai.

Mr. M. L. Garga, Municipal Engineer, Agra.

Mr. S. B. Sujan, District Engineer, Concrete Association of India, Bharat Buildings, Madras.

Mr. N. P. Sanjana, Engineering Assistant, Chief Engineer's Office, Bombay Port Trust.

Mr. K. M. Bedekar, Executive Engineer, Public Works Department, Ahmadnagar.

Sardar Bahadur T. S. Malik, C.I.E., Superintending Engineer, Central Public Works Department.

Mr. Gokal Chand, Assistant Engineer, Public Works Department, P. O. Kanki Raipur District.

Mr. Balwant Singh Budhiraja, State Engineer, Nabha.

Rai Bahadur Sri Narain, Chief Engineer, Cawnpore Improvement Trust.

Mr. A. B. Whitby, Executive Engineer, Public Works Department, Lashio, Northern Shan States, Burma.

Mr. D P. Dave, S.D.O., District Council, Basim (Berar).

Mr. Indra Narain Khanna, Asphalt Road Engineer, Standard Vacuum Oil Co., Delhi.

Rai Bahadur Sunderlal, Superintending Engineer, Public Works Department, Nagpur.

Mr. P. D. Ratnagar, Executive Engineer, Public Works Department, Jubbulpore.

Mr. R. A. Pereira, District Board Engineer, Coimbatore, South India.

Mr. J. C. Hardlikar, Executive Engineer, Public Works Department, Parbhani, (Nizams Dominions).

Mr. S. K. Madhav, Assistant Engineer, Indore City Municipality.

Mr. W. F. Walker, Executive Engineer, Public Works Department, Agra.

Mr. M. Eapen, Municipal Engineer, Bezwada.

Mr. A. Nageswara Ayyar, Special Engineer for Road Development, Madras

Mr. P. L. Bowers, Chief Engineer, Jaipur State.

Mr. H. V. Chapman, Executive Engineer, Burma Public Works Department, Bhamo.

Mr. Gopal Singh Nat, Assistant Surveyor of Works, M. E. S., Peshawar.

Mr. R. A. Fitzherbert, Superintending Engineer, Public Works Department, Bombay.

Mr. K. C. Khatri, S D.O., P.W.D., Shahbazgarhi, Tehsil Mardan, N.W.F.P.

Mr. G. Seshagiri Rao, Executive Engineer, Krishnaraja Sagara, Mysore State.

Mr. W. H. Rowlands, Technical Assistant, Burmah-Shell Oil Co., Ltd , Calcutta.

Mr. W. A. Griffiths, Roads Assistant, Burmah-Shell Oil Co., Ltd., Calcutta.

Mr. V. N. Rangaswami, Road Engineer, Burmah-Shell Co., Madras.

Mr. Ian A. T. Shannon, Technical Expert, Burmah-Shell Co., Madras.

Mr. Balvant Vithal Vagh, Road Engineer, Burmah-Shell Oil Distributing Company of India, Ltd., Bombay.

Mr. M. G. Banerjee, Controller of Stores, Calcutta Corporation.

Mr. D. N. Endlaw, Civil Landing Ground, Gaya.

Mr. K. S. Raghavachary, Assistant Engineer, Ganjam District Board, Chicacole.

Rai Sahib Tulasidas Banerji, Assistant Garrison Engineer, Jubbulpore.

Rai Sahib Sant Ram Sahgal, State Engineer, Mewar State, Udaipur.

Mr. Mohammad Abu Taraib, Superintending Engineer, Hyderabad (Deccan).

Mr. M. R. Duraiswami, Municipal Engineer, Kumbakonam.

Mr. T. Lokanatha Mudaliar, District Board Engineer, East Tanjore, Nagapatam S. I. R.

Rao Bahadur K. J. Gandhi, State Engineer, Junagadh (Kathiawar).

Mr. H. F. Marker, Superintending Engineer, Mysore Public Works Department, Bangalore.

Mr. R. W. Scaldwell, Superintending Engineer, Mysore, Bangalore.

Mr. W. H. Murphy, M.B.E., Municipal Executive Engineer, Bangalore.

Mr. J. W. Elwin, Assistant Engineer, Bangalore.

Mr. A. N. Thorpe, Consulting Engineer, Dholpur State, Dholpur.

Mr. M. A. Srinivasachari, Executive Engineer, Mysore Public Works Department Bangalore.

Mr. K. S. Ramamurti, District Board Engineer, Guntur District, Orgolo, (Madras Presidency).

Mr. Safdar Ali Shareef, Offg. S.D.O., Luxettipat Taluq Asifabad District Hyderabad (Deccan).

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Mr. K. Tirumalaiswami Ayyar, District Board Engineer, Madura.

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Mr. V. V. Patankar, Executive Engineer, Mysore, P.W.D., Mysore.

Mr. N. Narasimha Iyengar, Assistant Engineer, No. 2 Sub-Division, Mysore, Public Works Department, Dodballapur.

Rai Sahib K. C Gue, District Engineer, Jalpaiguri, (Bengal).

Mr. N. Subba Rao, Executive Engineer, Public Works Department, Bangalore Division, Bangalore.

Diwan Bahadur N. N. Ayyanger, Chief Engineer of Mysore.

Mr. H. Hughes, Chief Engineer, Burma Public Works Department, Rangoon.

Mr. H. J. Tonks, Offg. Chief Engineer, Rangoon Corporation, Rangoon.

Mr. A. Oram, Superintending Engineer, Public Works Department, Peshawar.

Capt. W. G. Land-Anderson, Executive Engineer, Public Works Department, Mardan (N. W. F. P.).

Mr. Vishnu Parashuram Kanhere, State Engineer, Bhor State.

Mr. V. S. Rangaswami, Assistant Engineer, District Board, West Tanjore.

Rao Bahadur Lakshminarayana Aiyar Venkatakrishnan, Superintending Engineer, Tanjore Circle, Tanjore, South India.

Mr. R. L. Varma, Executive Engineer, Public Works Department, Tezpur (Assam).

Mr. N. Balakrishnan, District Board Engineer, Guntur District.

Mr. G. B. Vasvani, Assistant Engineer, Roads, Karachi Municipality.

Mr. G. P. Ray, District Engineer, Puri.

Mr. M. P. Cherian, Municipal Engineer, Tuticorin (South India).

Mr. Shanker Rau Panje, District Board Engineer, Kistna District, Chilakalapudi.

Mr. Joti Prasad, District Engineer, Narsinghpur.

Mr. Iqbal Narain Mehta, Municipal Engineer, Multan.

Mr. Hari Shanker Sharma, District Board Engineer, Meerut.

Mr. K. V. Srinivasamurti, Assistant Engineer, Kolar (Mysore).

Mr. P. G. Mathew, District Board Engineer, Vizagapatam District, Bobbili.

Mr. Uttam Chand Gaur, Offg. Garrison Engineer, Military Engineer Services Quetta.

Mr. K. B. Devasthala, District Engineer, District Council, Yeotmal, C.P.

Mr. Ramchandra Subrahmanyam, Executive Engineer, Madura Municipality.

Mr. T. C. Gue, Chief Engineer, Rewa State.

Mr. C. P. Saksena, Assistant Engineer, Rewa State.

Mr. M. R. Jimajani, State Engineer, Porbander.

Mr. N. S. Joshi, Assistant Engineer, Poona.

Mr. S. B. Rege, Executive Engineer, Sind Public Works Department, Nawabshah.

Mr. E. G. Bullen, Offg. Executive Engineer, Southern Shan States, Soilem (Burma).

Mr. H. A. Keatinge, Executive Engineer, Public Works Department. Chittagong.

Mr. N. D. Gupta, Asphalt Engineer, Standard Vacuum Oil Co, Calcutta.

Mr. J. Vesugar, Under Secretary to the Govt. of the Punjab, P.W.D.

Mr. F. H. Hogshaw, Superintending Engineer, P.W.D., Central Circle, Writers Buildings, Calcutta

Mr. K. J. Shivdasani, Chief Officer and Engineer, District Local Board, Larkana

Mr. J. M. Fetters, District Representative of Caterpillar Tractor Co., Calcutta.

Mr. H. B. Parikh, Special Road Engineer in Sind, Karachi.

Mr. P. V. Chance, P.W.D., Raipur, C.P.

Mr. J. M. Todd, Executive Engineer, Moulmein Division, P.W.D., Moulmein, Burma.

Mr. G. E. Scott, Superintending Engineer, Taunggyi, Shan States, Burma.

Mr. R. McIntosh, Executive Engineer Waltair, Vizagapatam District, Madras Presidency.

Mr. C. E. de la Nougerede, Assistant Garrison Engineer, Calcutta Division, Calcutta.

Mr. J. F. H. Nicolson, Chief Public Works Officer, Federated Shan States, Taunggyi, Burma.

Mr. R. Trevor Jones, Superintending Engineer, P.W.D., B. & R Branch, Punjab.

Mr. C. A. Brown, Executive Engineer, Motihari Division, Motihari (Bihar).

Mr. S. C. Chatterjee, Superintending Engineer, Central Circle, Calcutta.

Rai Bahadur Chhuttan Lal, Retired Chief Engineer, the Mall, Lucknow.

Mr. A. Brebner, C.I.E., Chief Engineer, Central P.W.D., Simla

Mr. C. D. N. Meares, C/o Standard Vacuum Oil Company, Calcutta.

Mr. H. A. Hyde, Chief Engineer, P W D, Central Provinces.

Major W. B. Wishaw, O.B.E, M.C., R.E., Engineer-in Chief's Branch, Army Headquarters, Simla.

Mr. G. M. Ross, Chief Engineer and Secretary to the Government of the N.W.F.P., P.W.D.

Mr. Murari Lal, Assistant Engineer, P.W.D., Rohtak.

Captain James Stuart, Executive Engineer, P.W.D., Bannu.

Mr. S. C. Dam, Executive Engineer, Rajshahi Division, Rajshahi, Bengal.

Mr. T. V. Sundaresan, Bangalore.

Captain Roscoe Clayton, Garrison Engineer, Wana, Waziristan.

Captain W. B. Gunnell, Messrs. Ford & Macdonald Ltd., Varma Building, Connaught Place, New Delhi.

Lt. Col. W. deH. Haig, D.S.O., Chief Engineer, P.W.D., B. & R. Branch, United Provinces.

Mr. F. D. Wellwood, Chief Engineer, Mayurbhanj State, Eastern States Agency, Baripade.

Mr. F. A. Betterton, Chief Engineer, P.W.D. Bihar.

Mr. R. A. Kerr, C/o. The Burma Oil Co. Ltd., Rangoon.

Mr. C. L. Berg, Executive Engineer, P.W.D. Offices, Chepauk, Madras.

Mr. A. E. C. Morris, Branch Manager, McKenzies Ltd., Esplanade, Madras.

Mr. W. L. Murrel, Offg Superintending Engineer, Chhota Nagpur Circle, Ranchi.

Mr. A. N. Chopra, Executive Engineer, P.W.D , Taungao, Burma.

Mr. M. H. Naqvi, Executive Engineer, P.W.D., Bhir Hyderabad (Deccan).,

Mr. G. A. M. Brown, Superintending Engineer, P.W.D., N.W.F.P., Bannu.

Mr. Mahabir Prasad, I.S E., Executive Engineer, P.W.D. (B & R), Agra.

Brigadier E. C. Walker, Chief Engineer, Southern Command, Poona.

Mr. Prem Nath, District Engineer, Holkar State, P.W.D., Garoth (C. I.)

Mr. S. N. Tripathi, Asst. Engineer, P.W.D., C.P., Chhindwara.

Mr. J. C. Guha, Executive Engineer, P.W.D., Burdwan Division, Hoogly.

Mr. M. A. Rangaswamy, District Engineer, Darbhanga (Bihar).

Mr. F. L. D. Wooltorton, Executive Engineer, Meiktila Division, (Buildings & Roads), Meiktila.

Mr. D. P. Nayar, P.W.D., Buildings and Roads Branch, Lahore.

Mr. Ali Ahmad, Superintending Engineer, P.W.D., Assam, Shillong.

Mr. Ramesh Chandra, Executive Engineer, Lower Assam Division, P.W.D., Gauhati, (Assam).

Mr. H. G. Cocksedge, P.W.D. (Assam) Shillong.

Mr. D. C. Datta, P.W.D., Dibrugarh, (Assam).

Mr. Sudhindra Kumar Datta, Asst. Engineer c/o Executive Engineer, Khasi & Jaintia Hills Division, Shillong.

Mr. K. E. L. Pennel, Superintending Engineer, P.W.D., Shillong, (Assam).

Mr. F. E. Cormack, Executive Engineer, Khasi & Jaintia Hills Division, P.W.D., Shillong (Assam).

Mr. B. C. Das, Sub-Engineer, Local Board, Tezpur, (Assam).

Mr. Faqir Mohd. Khan, Executive Engineer, P.W.D., Dera Ismail Khan.

Mr. P. Venkataramana, Executive Engineer, P.W.D., Bezwada (Madras Presidency).

Mr. R. N. Dogra, Apprentice Engineer, 1st Lahore Provincial Division, Lahore.

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Mr. S. S. Sharma, Asst. Engineer, P.W.D., Benares Provincial Division, Benares.

Mr. D. S. Desai, C/o Messrs. Braithwaite & Co., (India), Ltd., Calcutta.

Mr. Raj Mohan Nath, Asst. Engineer, P.W.D., Assam, Nowgong P.O.

Mr. Bidhubusan Chaudhury, Asst. Engineer, P.W.D., Assam, Shillong.

Mr. B. N. Bose, Asst. Engineer, P.W.D., Bengal, Calcutta.

Mr. W. T. Eccleston, Executive Engineer, Multan.

Mr. M. D. Bharucha, C/o The All India Construction Co., Ltd., Bombay.

Mr. C. S. Venkatasubrahmanya Iyer, District Board Engineer, Nilgiris, Ootacamund.

Mr. K. V. Karve, Asst. Engineer, P.W.D., Mysore, Shankarapuram, Basavangudi Post, Bangalore City.

Mr. W. Lawley, Executive Engineer, P.W.D., Mardan.

Mr. K. Subba Rao, Municipal Engineer, Guntur.

Mr. S. K. Banerji, Assistant Engineer, Rewa (Central India).

Rai Sahib Kidar Nath, Sub-Divisional Officer, Public Works Department, B. & R. Branch, Jullundur Cantt.

Mr. A. W. Nightangle, Superintending Engineer, Dowlaishweram Circle, Dowlaishweram (Madras Presidency).

Rai Sahib J. N. Gupta, Sub-Divisional Officer, P.W.D., Shillong, (Assam).

Mr. G. N. Dutt, Sub-Divisional Officer, Public Works Department, Kohima, (Naga Hills, Assam).

Mr. M. S. Duraiswami Ayyangar, Executive Engineer, Public Works Department, Kottayam (Travancore).

Mr. C. M. Shahani, C/o Braithwaite & Co., (India) Ltd., Calcutta.

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Mr. P. T. Narayana Nayar, District Board Engineer, Tinnevelly (Madras Presidency).

Mr. K. S. Gangadhara, Assistant Engineer, Kadur (Bangalore).

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Mr. H. P. Sinha, Executive Engineer, Central Public Works Department, New Delhi.

Mr. Vaman J. Kunti, State Engineer, Jamkhandi.

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Mr. C. F. Hunter, Deputy Chief Engineer, P.W.D., Buildings and Roads Branch, Lucknow.

Mr. D. H. Ranade, B.E., C/o Messrs. Ranade Bros., Engineers and Contractors, Poona 2.

Mr. A. Eastmond, M.C., I.S.E., Executive Engineer, Kumaun Division, Nainital.

Mr. P. K. Mukherji, District Board Engineer, Cocanada, (East Godavari), Cocanada.

Mr. J. Bakshi, Executive Engineer, Cuttack.

Mr. G. B. Sankaram, L. F. Assistant Engineer, Amalapuram, East Godavari District, Madras Presidency.

Mr. V. A. Dighe, Chief Engineer, Janjira State, Janjira Murud.

Mr. A. Burns Lawson, The Hindustan Construction Company Limited, Bombay.

Mr. D. B. Pancholi, State Engineer, Dhrangadhra State, Dhrangadhra (Kathiawar).

Mr. N. P. Sundaram Pillai, District Board Engineer, Trichinopoly.

Mr. A. W. H. Dean, Superintending Engineer, Central Public Works Department, New Delhi.

Mr. J. Kurian, Engineer to the Corporation of Madras, Madras.

Mr. Ulfat Rai Chaddha, Mohan Newas, P. O. Ichhra, Lahore.

Mr. S. P. Chowdhury, Assistant Engineer, P. O. Gohpur, Distt. Darranga, (Assam).

Mr. J. N. Das Gupta, Assistant Engineer, Delhi Municipal Committee, Delhi.

Mr. C. M. Bennett, Executive Engineer, Public Works Department, Koraput Division, Koraput, (Orissa).

Mr. M. S. Bisht, Assistant Engineer, Public Works Department, Naini Tal.

Mr. M. I. D. Mufti, Garrison Engineer's Office, Fort William, Calcutta.

Mr. A. Stuart Lewis, The Concrete Association of India, Calcutta.

Mr. S. Ramanujacharya, Assistant Engineer, Public Works Department, Koraput, Via Salvi, (B. N. Rly.).

Captain J. R. Hainsworth, Executive Engineer, Peshawar Canals Division Peshawar.

Mr. A. V. Gharpure, C/o The Indian Hume Pipe Co., Ltd., Delhi.

Mr. Gopal Das, Sub-Divisional Officer, Public Works Department, Hissar.

Mr. M. M. Doshi, C/o The Indian Hume Pipe, Lucknow.

Mr. R. K. Sarkar, Municipal Engineer, Lucknow.

Mr. V. M. Meswani, Indian Hume Pipe Company, Lucknow.

Mr. Charn Chandra Bagchi, Sub-Divisional Officer, Lucknow University, Lucknow.

Mr. Upendra J. Bhatt, State Engineer, Public Works Department, Bhavnagar State, Bhavnagar.

Mr. Abid Reza Choudhury, Sub-Divisional Officer, Public Works Department, P. O. Goalpara, Distt. Goalpara, (Assam).

Mr. V. M. Sukhatankar, District Engineer, District Local Board, Belgaum.

Mr. O. C. Kutty Krishnan, Roads Engineer, The Standard Vacuum Oil Co., Mambichetty Street, Madras.

Mr. M. E. Lloyd, Asphalt Engineer, Standard Vacuum Oil Co., Calcutta.

Mr. P. Sirajuddin, District Board Engineer, West Tanjore, Tanjore.

Mr. D. J. Plumley, State Engineer, Jagdalpur, Eastern States Agency.

Mr. S. S. Bhagat, Executive Engineer, Meerut.

Mr. R. T. Burton, Standard Vacuum Oil Company, Karachi.

Mr. Dilbagh Singh Dhesi, State Engineer, Jind State.

Mr. M. P. Nagarsheth, Broach (Bombay Presidency).

Rai Sahib L. Fateh Chand, Secretary-Engineer, District Board, Bijnor.

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Mr. E. F. G. Gilmore, Director, Industrial Research Bureau, Indian Stores Department, Simla/Delhi.

Mr. B. C. De, Sub Engineer, P.W.D , Silchar (Assam).

Mr. H. Willcoks, Superintending Engineer, Central P.W.D., New Delhi

Mr. H. M. Shahani, Supervisor of Works, Hyderabad Sind Municipality.

Mr. A. S. Trollip, General Manager, The Bombay Electric Supply and Tramways Company, Limited, Bombay.

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Mr. H. R. Sayoji, Assistant Engineer, District Board, Kistna.

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Mr. N. D. Wale, Engineer, Municipal Borough, Hubli District, Dharwar.

Mr. M. N. Zutshi, Engineer, District Board, Gorakhpur.

Mr. S. Guruswami, Assistant Inspector of Local Works, Muzaffarpur.

Mr. N. N. Mehta, Simla Central Division, Simla.

Mr. A. N. Bose, Superintending Engineer, Central Circle, Calcutta.

INDIAN ROADS CONGRESS.

LIST OF ASSOCIATE MEMBERS.

September, 1936.

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Mr. Th. C. Marschalko, Chief Engineer, Texas, Co., India Ltd., Bombay.

Mr. C. G. Hogg, Representative of General Motors (India) Ltd., Bombay.

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Mr. J. P. Anderson, Dunlop House, Calcutta.

the Second Indian Roads Congress held in 1936, in which Colonel Haig pointed out very definitely the fact that there is the light cart as well as the heavy. Most road engineers will agree with Colonel Haig. As the cost of production of lighter pneumatic equipment should be less, and as this difference would doubtless decide many thousands of cart owners to modernise their light carts, would it not be a sound idea to cater early for this potential light-cart demand? Unless some such move as this is effected I feel sure that, after British and Indian interests have done the pioneering work, Japanese and German interests will invade the market with lighter and cheaper equipment.

There is one further point I would like to mention, and that is the part that wide, solid, rubber tyres might play in this work of improving the bullock cart wheel. One of the best papers I have seen on the correlation of impact, speed, and nature of tyre was that published in Volume 227 of the Proceedings of the Institute of Civil Engineers. The perusal of such papers would seem to indicate that the solid rubber tyre would not preclude the possibility of having a taper roller bearing, and that such a tyre might be an honest rival to the pneumatic tyre within bullock cart speeds. It is perhaps on this line that British and Indian interests may be attacked.

Mr. A. W. H. Dean (Delhi):—I feel that my personal experience in the last year may be of interest. A little time ago the municipality of New Delhi, of which I have been president for the last year, experimented with loaded bullock carts fitted with ordinary iron tyres and with pneumatic tyres to determine the difference in the wear of the road caused by them. They sent out two carts similarly loaded each round its own circle for a period of three months. The result was that the ordinary iron tyred cart completely destroyed the road, while the pneumatic tyred cart did little damage. The municipality got the local Government to make bye-laws restricting certain roads in New Delhi to carts fitted with pneumatic tyres only. They also wrote to the Local Public Works Department asking them to put a clause in their contract form limiting the use of vehicles either carts or lorries working on Puplic Works Department contracts to those fitted with pneumatic tyres only. This was done. We have had since two strikes of carters and *Thelawalas*, and as a result of the first strike in the hot weather the clause in the Public Works Department contracts was indefinitely suspended and up to now has not been reimposed. Very considerable modifications were also made by the local Government in the New Delhi bye-laws. So it will be seen that it does not pay to go too fast with that sort of thing. With regard to the last speaker who was speaking about the various types of pneumatic tyre equipment, I was myself going to ask the author of the paper if he could indicate approximately what type of equipment he meant when he said it could be bought for Rs. 150/- or Rs. 200/- per cart. I went into the question and found that the people who sell these things put forward four or more different types and as far as I remember it was only a very light type of cart which could be purchased for Rs. 150/-. The type of thing which we needed for carrying the ordinary Delhi contractor's load would cost about Rs. 450/-.

I should like to put another question to the author of the paper. Can he give any information, if he has any idea, as to the life of these pneumatic tyres. I know that the wear on them due to abrasion is very slight, but I personally think that there is a tendency for rubber tyres to perish in this country. Will these tyres give $2\frac{1}{2}$ to 3 years' service irrespective of whether they do 3,000 miles or 10,000 miles? I wonder if the author of the paper can give us any information on that point.

Colonel W. de H. Haig: (United Provinces):—Mr. Radice suggested just now that the road engineer might assist in the introduction of rubber-tyred carts